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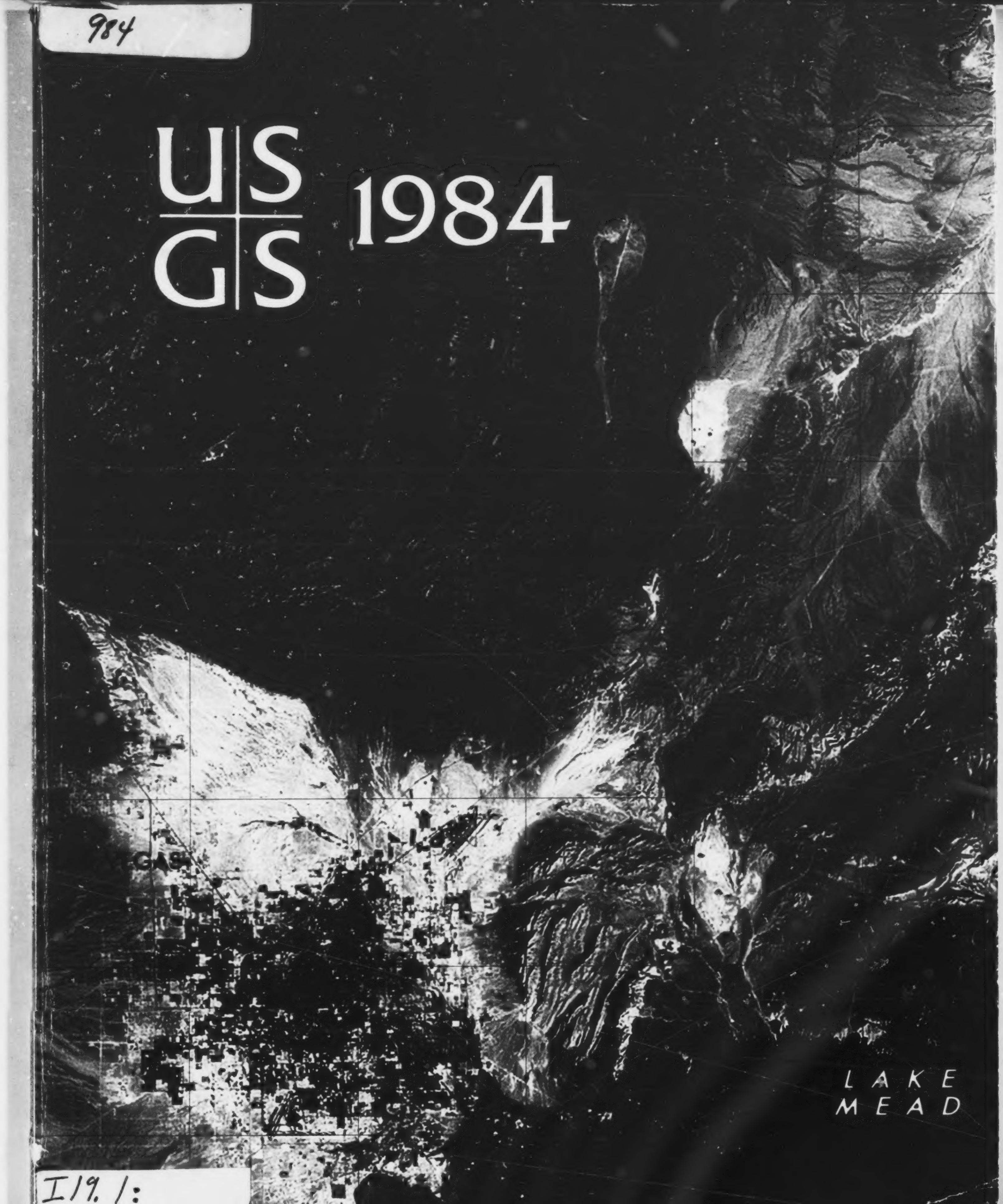
USGS 1984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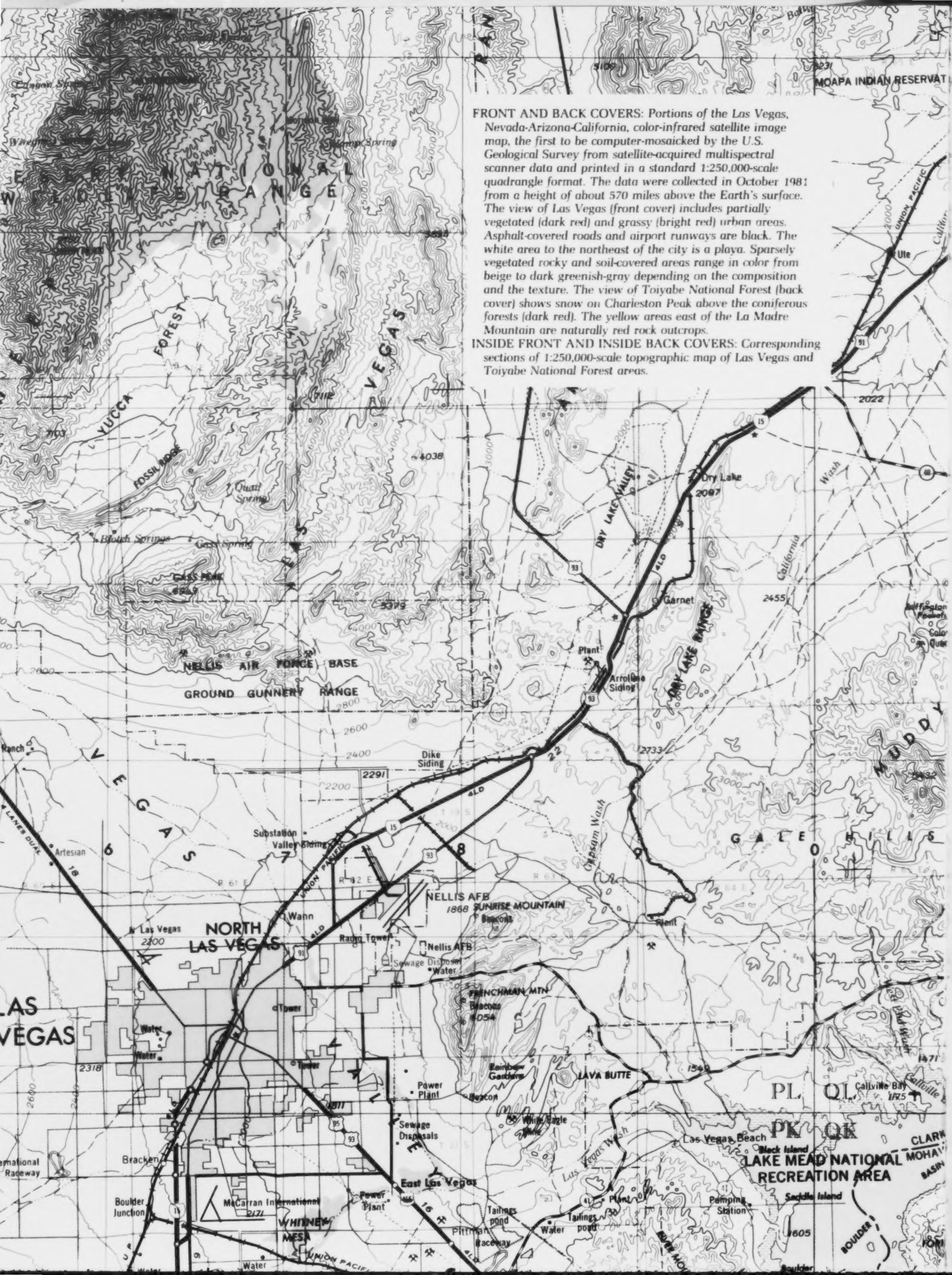
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YUCCA FOREST
FOSSIL RIDGE
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Blotch Springs
Gass Spring
GASS PEAK
Wiregrass Spring
Cow Spring
NELLIS AIR FORCE BASE
GROUND GUNNERY RANGE
LAS VEGAS
NORTH LAS VEGAS
VALLEY
DRY LAKE VALLEY
DRY LAKE RANGE
Dry Lake
Garnet
Arrolime Siding
Dike Siding
Substation
Valley Siding
Artesian
NELLIS AFB
SUNRISE MOUNTAIN
FRENCHMAN MTN
LAVA BUTTE
Rainbow Gardens
White Eagle Mine
Power Plant
Sewage Disposals
East Las Vegas
McCarran International
WHITNEY MESA
Boulder Junction
Bracken
Las Vegas Beach
Black Island
LAKE MEAD NATIONAL RECREATION AREA
Saddle Island
Callville Bay
GALE HILLS
MUDDY
Gypsum Wash
Las Vegas Wash
California Wash
Ute
Pittman
Pumping Station
CLARK
MOHAVE
UNION PACIFIC
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FRONT AND BACK COVERS: *Portions of the Las Vegas, Nevada-Arizona-California, color-infrared satellite image map, the first to be computer-mosaicked by the U.S. Geological Survey from satellite-acquired multispectral scanner data and printed in a standard 1:250,000-scale quadrangle format. The data were collected in October 1981 from a height of about 570 miles above the Earth's surface. The view of Las Vegas (front cover) includes partially vegetated (dark red) and grassy (bright red) urban areas. Asphalt-covered roads and airport runways are black. The white area to the northeast of the city is a playa. Sparsely vegetated rocky and soil-covered areas range in color from beige to dark greenish-gray depending on the composition and the texture. The view of Toiyabe National Forest (back cover) shows snow on Charleston Peak above the coniferous forests (dark red). The yellow areas east of the La Madre Mountain are naturally red rock outcrops.*

INSIDE FRONT AND INSIDE BACK COVERS: *Corresponding sections of 1:250,000-scale topographic map of Las Vegas and Toiyabe National Forest areas.*

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United States Geological Survey Yearbook, Fiscal Year 1984

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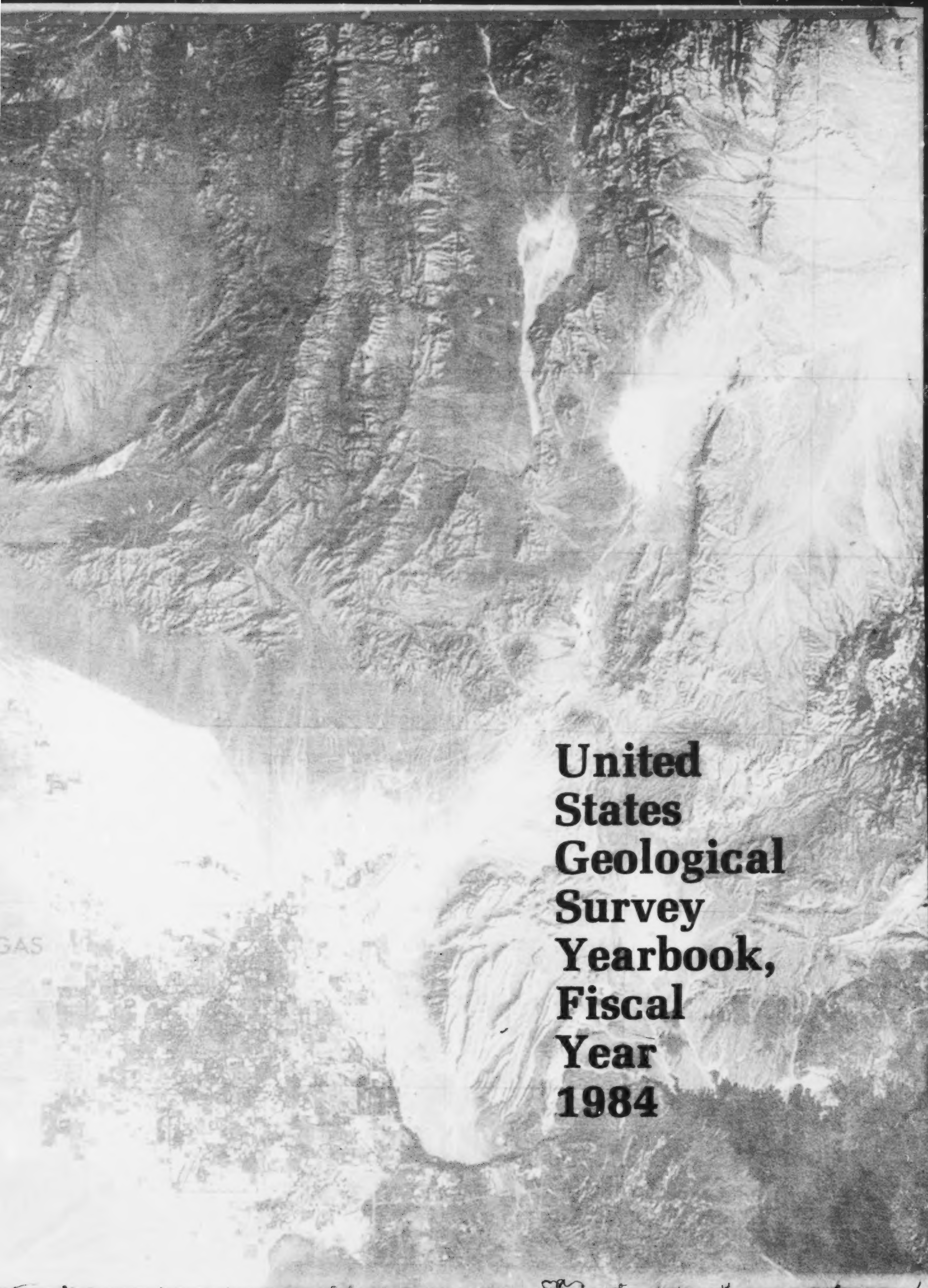

United States Geological Survey Yearbook, Fiscal Year 1984

DEPARTMENT OF THE INTERIOR
DONALD PAUL HODEL, Secretary

U.S. GEOLOGICAL SURVEY
Dallas L. Peck, Director

March 3, 1849

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The Year in Review

As the Nation's principal earth science research agency, the U.S. Geological Survey has a special responsibility to present an annual report of its investigations to the public it serves. In 1984, our endeavors included new investigations of natural phenomena, responses to urgent public concerns and legislation, and special efforts to adapt advanced technology that will make us more efficient in meeting the challenges that lie ahead. As Director, I am privileged to highlight here some of the results of the Geological Survey's many activities that are described in this *Yearbook*.

Natural events have played a crucial role throughout the agency's 105 years. Our formal earthquake program, for example, began 100 years ago in the wake of the Charleston, South Carolina, earthquake of 1886. In the past few years, work with natural hazards has become an increasingly significant part of our overall program. Since the explosive eruption of Mount St. Helens in 1980, we have increased greatly our monitoring efforts for other volcanoes of the Cascade Range. In 1984, we successfully predicted three of the four latest eruptions of Mount St. Helens. In Hawaii, Mauna Loa Volcano began erupting on March 25, 1984, and lava moved to a point 5 miles from the city of Hilo. Geological Survey scientists provided round-the-clock surveillance throughout the several weeks of the eruption. Earthquakes continue to pose a major threat to life and property in the United States. During this year, we have made considerable progress toward more effective automated monitoring networks, advanced our understanding of earthquake mechanisms, and begun an important earthquake prediction experiment at Parkfield, California. In addition to our progress in earthquake studies, landslide hazards have been the focus of new cooperative efforts with the States.

In response to intense droughts in the late 1970's, we established a comprehensive program to study the major regional aquifer systems of the United States. Studies of six of these aquifers were completed by 1984. The study for the High Plains regional aquifer resulted in the first accurate mapping of ground water depleted from the aquifer by irrigation and in a successful model to test alternative strategies for mitigating the effects of ground-water depletion. In striking contrast to the scarcity of water in the previous decade, storms and flooding were a major problem from 1982 through 1984. A record rise in the Great Salt Lake, for example, caused extensive damage to property. The lake rose 5 feet from September 1983 to July 1984, the second largest seasonal rise since 1847. These dramatic variations in natural processes require intensive scientific study for us to better prepare the public to cope with such hazards now and in the future.

In addition to natural events, public concerns and legislation related to earth science issues have played a large role in the direction of Geological Survey activities. Continuing national interest in energy supplies has led to important new accomplishments by our employees. In 1984, our energy studies located high-potential geothermal fluids at Newberry volcano, contributed to improved methods for estimating remaining oil and gas resources from past production records, and produced the first maps that will be the basis for a new atlas of oil and gas data. During the past year, we transferred management of the Barrow gas fields in Alaska to the North Slope Borough. A significant result of our North Slope studies before the transfer was the development of new methods for assessing oil and gas resources without damage to the fragile environments in cold regions.

During this year, we responded in new and positive ways to needs of other Federal agencies that deal with the national concern for adequate supplies of clean water. We provided major assistance in the development of the hydrologic part of the National Ground Water Protection Strategy formulated by the Environmental Protection Agency. Our investigations in this program involved the physical, chemical, and biological processes that affect the

Terminus of Columbia Glacier, as recorded by an automatic camera, on June 5, 1984 (top), and September 4, 1984 (bottom). The terminus ice cliff is 3.1 miles wide; the cliff was about 200 feet high on September 4. For scale, the dark island in the left foreground is 1,100 feet wide. Floating ice, including huge icebergs, chokes the water of Columbia Bay in front of the ice cliff. On June 5, a floating tongue of ice still is attached to the grounded glacier. Because of the rapid flow, virtually all the ice seen in the June 5 photograph had calved off and been replaced by new ice by September 4. (Photographs by Robert M. Krimmel, Water Resources Division, U.S. Geological Survey.)

movement and fate of hazardous substances in hydrologic systems. The effects of high selenium levels associated with irrigation return waters in the southwestern San Joaquin Valley of California became an issue of intense concern in 1984. Our scientists are working closely with colleagues in the Bureau of Reclamation, the Fish and Wildlife Service, and State agencies to identify geochemical pathways of the selenium in waters of the agricultural systems and wildlife lands of that area.

The worldwide availability of strategic minerals is another concern of critical national interest. In recent years, as the United States began to rely more on imports to satisfy mineral needs, the Geological Survey responded with new programs of basic research and evaluation of mineral resources. These programs have included the Conterminous United States Mineral Appraisal Program, a similar appraisal program of Alaska, and assessments of approximately 50 million acres of Federal wilderness lands throughout the country. The publication in 1984 of Professional Paper 1300, *Wilderness Mineral Potential*, was a significant milestone in our long-term efforts to thoroughly characterize the mineral wealth of the Nation. This comprehensive volume summarizes 20 years of cooperative studies with the Bureau of Mines and the Forest Service.

The establishment in 1983 of the U.S. Exclusive Economic Zone (EEZ) 200 nautical miles seaward from the Nation's coastline tremendously increased the area within which mineral and energy resources must be assessed. In 1984, the Geological Survey completed detailed geophysical surveys of the Juan de Fuca and Gorda Ridges in the Pacific in cooperation with the Hawaii Institute of Geophysics, completed sonar mapping of 250,000 square miles of the west coast EEZ, and conducted a major scientific cruise to identify likely areas of potential seafloor minerals in the zone surrounding United States island territories in the Pacific. In addition to exploration of the EEZ, Geological Survey crews on the Research Vessel *Samuel P. Lee* accomplished the first comprehensive geophysical survey of the Antarctic continental margin to be made by an American expedition. An intensive multidisciplinary resource appraisal program for the EEZ, begun in 1984, will be continued, concentrating on specific geologic provinces within the zone. The Nation must establish a solid scientific framework for the exploration and development of this new frontier, because the beginning of resource development by industry in the EEZ will depend on there being sufficient evidence that a substantial potential exists for energy and mineral resources.

By far the most pervasive technological change affecting us in recent years has been the greatly expanded use of computers. The automation of spatial data has made it possible to create digital models of the Earth's surface, for both natural and manmade features. These basic spatial data can be manipulated and combined in any desired format in the computer. Products designed and prepared on the computer have become part of our routine mapping processes. Together, the various types of digital cartographic data that are being assembled constitute the National Digital Cartographic Data Base. We continue to compile and manage large volumes of resource data, including data on water, coal, petroleum, and mineral resources, in digital data bases. Not only have we developed the means to acquire and store these diverse data, but we also have developed innovative new programs to manipulate and effectively use these large volumes of data; for example, our water simulation models mathematically evaluate the effects on water quantity and quality from such complex and interrelated causes as changes in rainfall and irrigation pumping rates.

An essential part of the Geological Survey mission has always been the dissemination of the results of scientific data collection and research. During this year, we published more than 4,900 technical reports and 6,600 new maps, which are still our primary channels of information dissemination. Our dissemination function has been enhanced by the use of digital data and direct computer access to make information more readily available to the public. The National Cartographic Information

Center provides access points across the country for machine-readable tapes of cartographic and geographic data. The National Water Data Exchange functions as a clearinghouse for locating and facilitating access to water resource data. New procedures for managing information in the National Digital Cartographic Data Base will result in significant overall savings to the Federal Government. In cooperation with the Bureau of the Census, we are preparing digital 1:100,000-scale map data for the entire conterminous United States that will provide essential support to the 1990 Decennial Census.

An important new publication that deserves special mention is the *National Water Summary*, an annual overview of water conditions and concerns throughout the Nation. In 1984, we issued the first summary, and the second edition is now in the advanced stages of preparation. The information in each *Summary* is obtained through research and investigations supported by many of the 800 State and local agencies that are cooperators in our Federal-State Cooperative Program and by other Federal agencies.

Finally, on a more personal note, but one that I am certain is shared by all my colleagues: The high point of the year for me was the opportunity in September to honor two of the finest leaders of the Geological Survey family, Dr. Thomas B. Nolan and Dr. Vincent E. McKelvey. Tom was presented with a 60-year pin and a letter from the President congratulating him for his long service to the Nation. We surprised Vince by dedicating our new annual forum on energy and mineral resources as the McKelvey Forum. These two men have between them more than 100 years of service as geologists, public servants, and Directors of the U.S. Geological Survey. We could ask for no finer examples to guide us as we pursue our second century of providing "earth science in the public service."

The foresight of the Geological Survey's past leaders in encouraging the highest standards in our work and in the hiring of highly professional people at all levels has enabled us to build on their foundation and make a real contribution to the needs and progress of the Nation. As we face new challenges in future years, we must continue to maintain our historic standards of excellence and to strive for the highest levels of accomplishment. Our success will depend on the awareness, enthusiasm, and commitment of our people for their strong tradition of serving the Nation as its principal source of earth science information.

Dallas L. Peck

Director

Perspectives

1:100,000-Scale Digital Cartographic Data Base For Federal Requirements

By Stephen C. Guptill

BACKGROUND

The increasing demand of the Nation's natural resource managers for the manipulation, analysis, and display of large quantities of earth science data has necessitated the use of computers and the building of geographic information systems. Traditional data formats and manipulation techniques are inadequate to meet the demands of today's scientists and information analysts. In the past, most data were presented as maps, tables, and textual reports. Each organization collected data in a different way and produced their output in various formats. The scales of such graphics as maps are different, the data codes used to identify certain elements differ from agency to agency, and the data formats are difficult to correlate; for example, geologic data in map form are difficult to correlate with census tabulations in computer-readable form. Such data formats are difficult to change, thus slowing the evaluation process. Usually, data prepared and presented in a form to address specific problems do not lend themselves to the consideration of alternatives, and it is time consuming to incorporate new data into out-of-date graphic materials. To help overcome these problems, computers and geographic information systems can provide a common language. These systems require, in digital form, the spatial data on map products. Only recently has it become technologically feasible and cost-effective to assemble and use data bases containing large amounts of digital spatial data.

For a number of years, the U.S. Geological Survey has been pursuing the development of a Digital Cartographic Data Base. The initial plans were for the data base to consist of boundaries, public land net, streams and water bodies, and transportation features shown on 1:24,000-scale maps; elevation data largely obtained concurrently with the orthophotoquad program; planimetric features from the 1:2,000,000-scale sectional maps of the *National Atlas of the United States of America*; elevation data obtained from the 1:250,000-scale map series; land use and land cover and associated map data; and geographic names. Because of a number of technological developments and programmatic opportunities, the scope of the data base has been increased to include digital cartographic data collected from 1:100,000-scale base maps. These data will provide complete coverage of such transportation features as roads, railroads, powerlines, and pipelines and such hydrographic features as streams, rivers, and water bodies. This major new effort will attempt to achieve nationwide coverage by the end of the decade.

The decision to create this data base was reached, in part, through the combination of two forces: the maturing of efficient and economical data capture technology and the requirements expressed for a major use of the data. The 1:100,000-scale map series was designed to facilitate automated data capture; for example, by raster scanners. The methodologies and procedures used in the data capture process have developed enough so that we can take advantage of the design features of the 1:100,000-scale maps and rapidly build a digital cartographic data base. Once these data are produced, the U.S. Bureau of the Census intends to use them as the cartographic framework of their geographic support system for the 1990 Decennial Census. The collaboration of a major data producer with a major data user at the inception of this project augurs well for the successful creation of an intermediate-scale digital cartographic data base that will meet national needs.

DATA BASE DESCRIPTION

1:100,000-Scale Maps

In the mid-1970's, the Geological Survey began its program of 1:100,000-scale mapping. The level of content was determined mainly by evaluating the content of the 1:24,000-scale maps. Each feature shown at 1:24,000 was evaluated and designated "include" or "exclude" at 1:100,000. The drawing (feature separate) on which the feature would be shown also was determined. The color-separation system of map production, in which a separate drawing is prepared for each color to be printed, was expanded to a feature-separation system. In the new system, such major components of the map as roads and hydrography are subdivided into classes, and separate master scribed drawings are prepared for each class (fig. 1).

The framework and content of the 1:100,000-scale base maps are derived primarily from 1:24,000-scale maps, with updates during the production process. This production process generally has the following phases: (1) reducing larger scale maps to 1:100,000 scale and mosaicking on the Universal Transverse Mercator projection, (2) updating the mosaicked base, (3) scribing the planimetric feature separate manuscripts, (4) scribing the contour manuscript, and (5) printing the complete metric topographic edition. If the base map material is less than 3 years old, only major features are updated. Material older than 3 years often requires more extensive planimetric updating. High-altitude aerial photographs are frequently used as the source of the update (figs. 2, 3).

A number of design characteristics of the 1:100,000-scale maps were chosen for compatibility with automated digitizing techniques. These

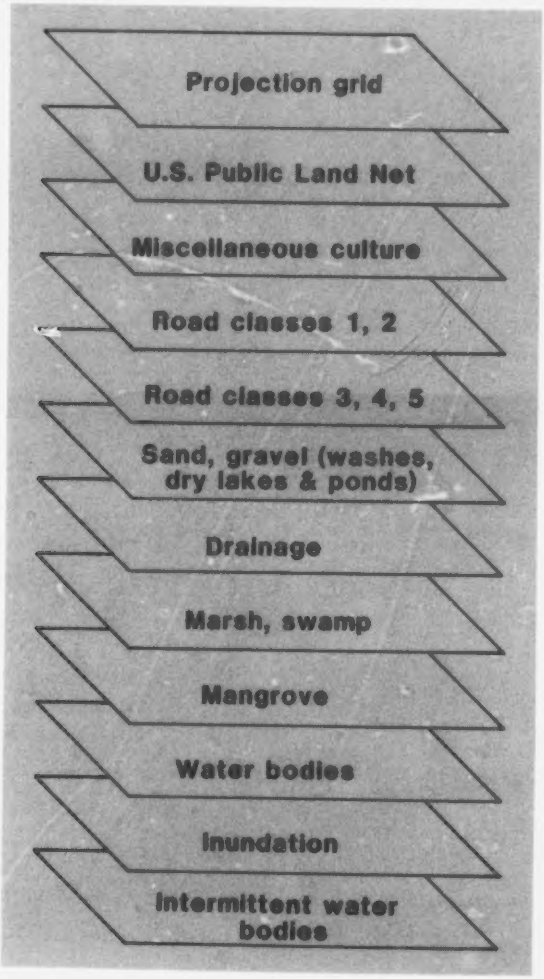

Projection grid
U.S. Public Land Net
Miscellaneous culture
Road classes 1, 2
Road classes 3, 4, 5
Sand, gravel (washes, dry lakes & ponds)
Drainage
Marsh, swamp
Mangrove
Water bodies
Inundation
Intermittent water bodies

Figure 1. *Feature separates used in preparing 1:100,000-scale digital data base.*

Figure 2. *Portion of Tallahassee, Florida, 1:100,000-scale metric topographic map, 1977 edition. Map compiled from U.S. Geological Survey 1:24,000-scale topographic maps. Planimetry revised from aerial photographs and other source data.*

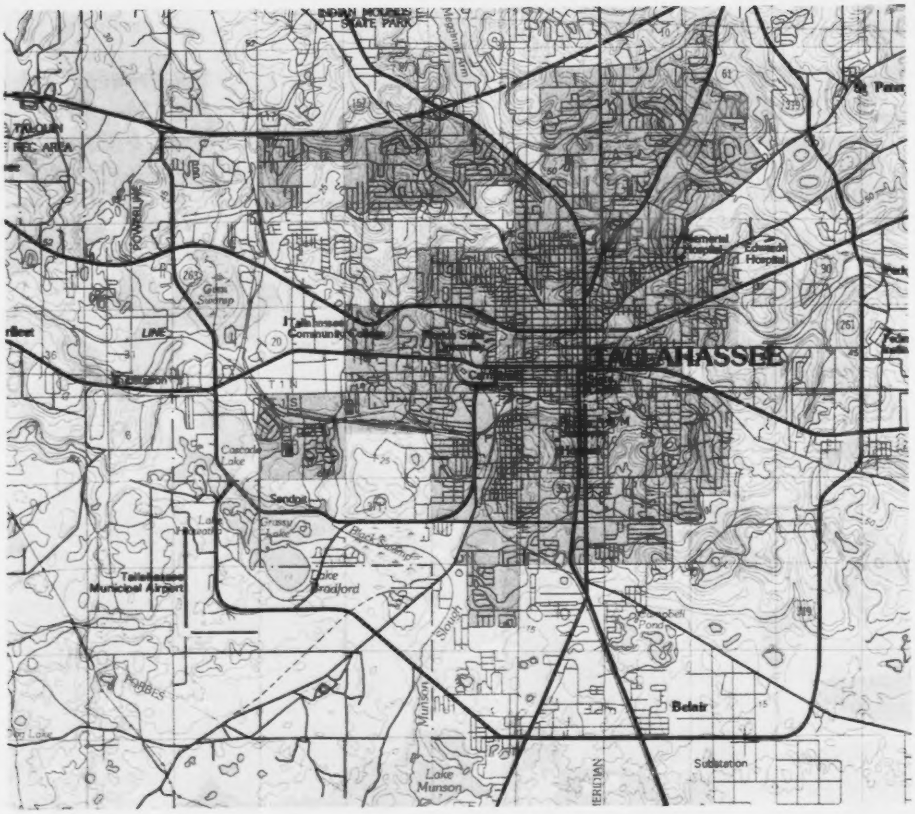
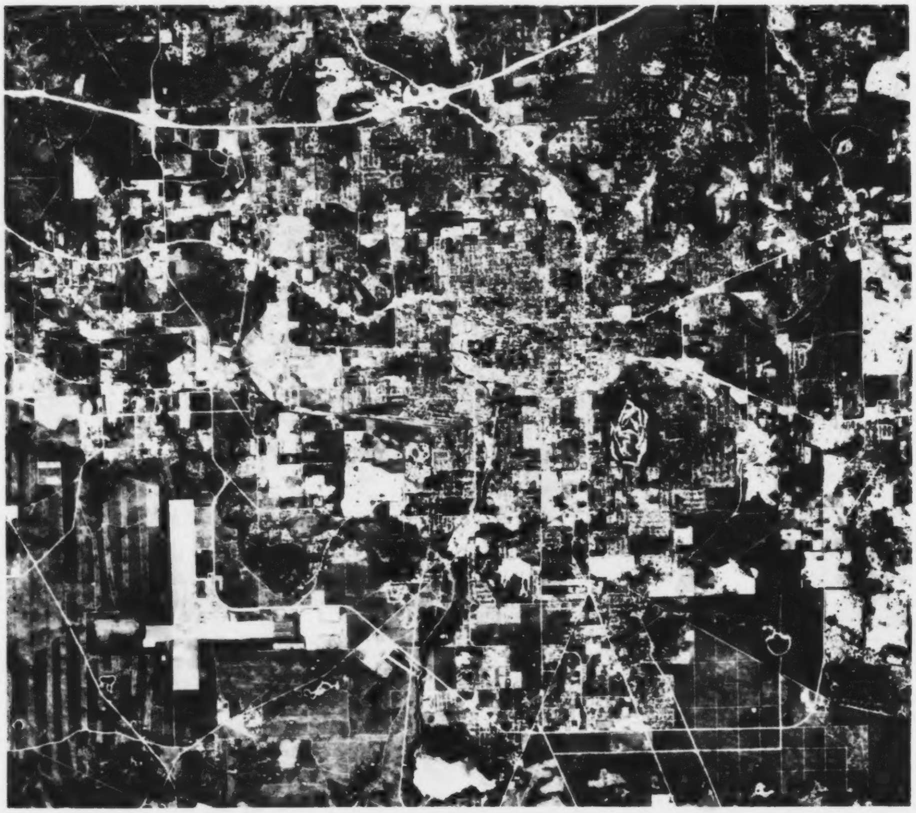

INDIAN MOUNDS STATE PARK
Meginnis Arm
TALQUIN REC AREA
POWERLINE
Gum Swamp
LINE
Tallahassee Community College
TALLAHASSEE
Memorial Hospital
Edwards Hospital
Cascade Lake
Sandpit
Lake Hiawatha
Grassy Lake
Black Swamp
Lake Bradford
Tallahassee Municipal Airport
FORBES
Munson Slough
Lake Munson
MERIDIAN
Campbell Pond
Belair
Substation
T 1 N
T 1 S
20
263
61
319
90
261
363
373
36
6
25
50
15

Figure 3. *Aerial photograph covering the same area as (fig. 2) used to update information.*



characteristics include the feature separation of materials during map compilation, a decrease or simplification of symbolization of linear features, such as roads represented by solid road symbols instead of cased road symbols, and a reduction in the number of features represented by discontinuous lines, such as intermittent streams shown by solid lines instead of dashed lines.

The Geological Survey is attempting to capitalize on these design characteristics and is gathering the bulk of the digital data using automated digitizing techniques. A Scitex Response 250 system is being used to scan the feature separates (fig. 4) for the roads and stream network. Interactive editing of the raster data (fig. 5) is performed on the Scitex and is followed by raster-to-vector conversion (fig. 6). The vector data are edited

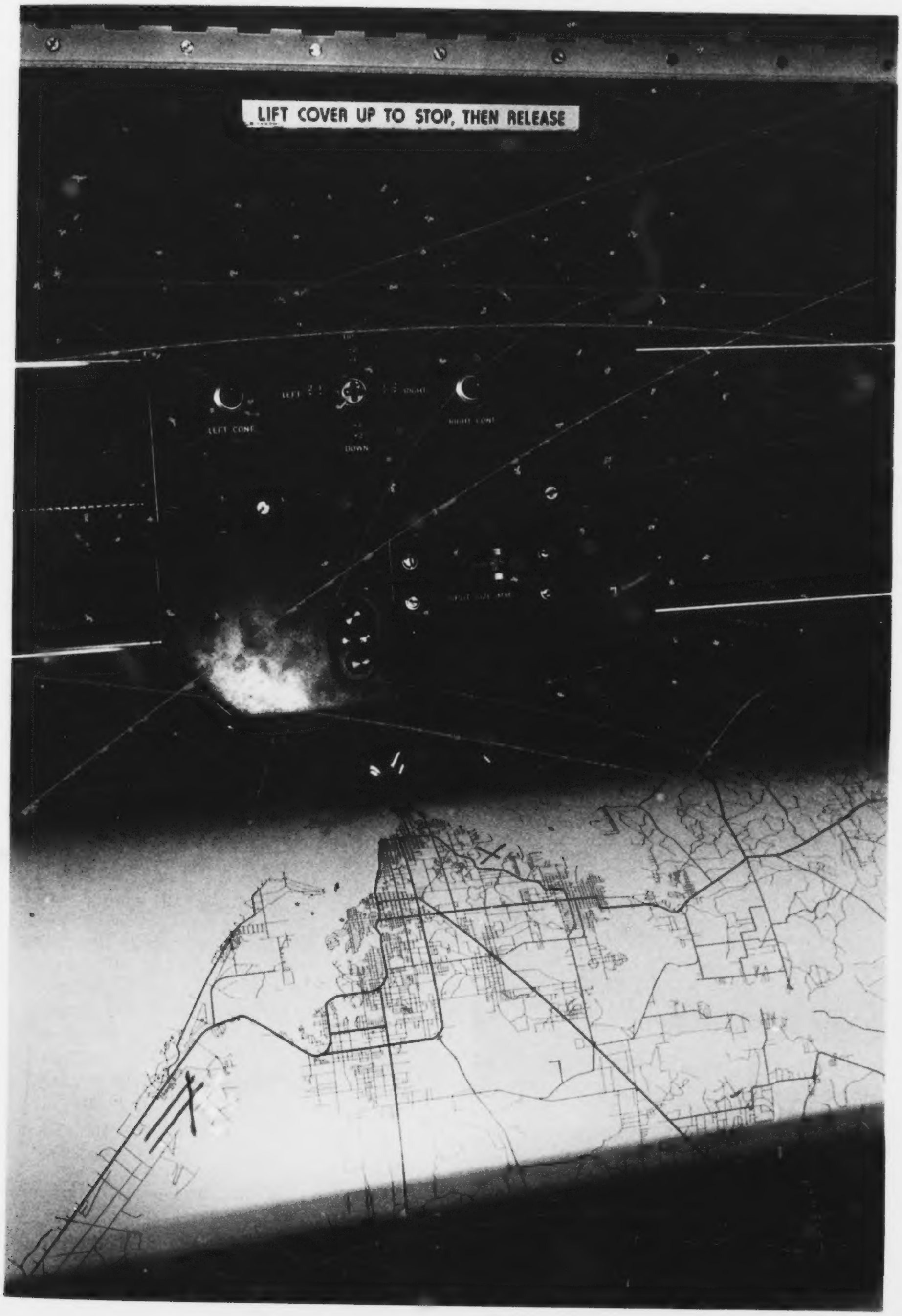


Figure 4. *Roads separate being scanned on Scitex scanner.*

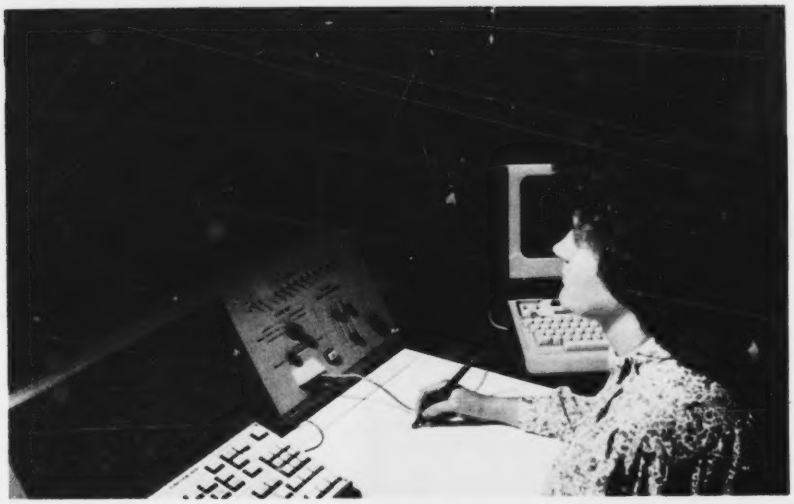


Figure 5. Scitex edit station display of roads data as scanned.

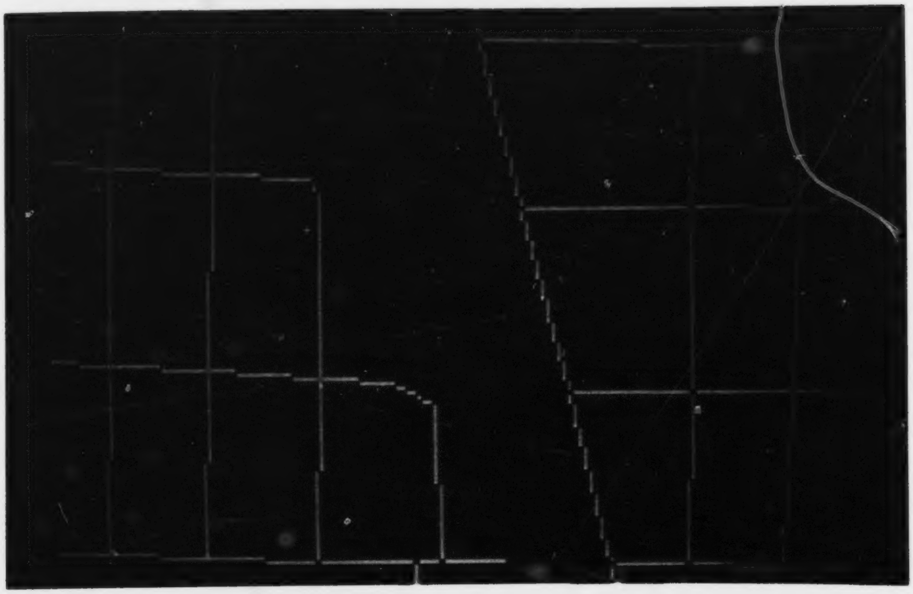


Figure 6. Scitex edit station display of vectorized roads data.

Figure 7. Interactive work station used to add attribute codes.

further and tagged (fig. 7) on an Intergraph edit station, with final structuring to a digital line graph format occurring on an Amdahl mainframe computer. It is believed that this production system will enable us to produce, at a high rate, large amounts of digital cartographic data.

Features Included in the Data Base

The data base will provide comprehensive coverage of transportation and hydrographic features. A complete list of the features to be included is given in table 1. These features provide a basic

Table 1. *Features included in 1:100,000-scale digital data base*

Transportation features

- Airport, airfield, landing strip
- Heliport
- Pipeline
- Power substation
- Power transmission line
- Railroads and related features
  - Bridge
  - Carline
  - Ferry
  - Roundhouse
  - Sidings
  - Snowshed
  - Station
  - Tracks, narrow gage
    - Juxtaposition
    - Multiple
    - Multiple, abandoned
    - Multiple, dismantled
    - Multiple, under construction
    - Single
    - Single, abandoned
  - Tracks, standard gage
    - Juxtaposition
    - Multiple
    - Multiple, abandoned
    - Multiple, dismantled
    - Multiple, under construction
    - Single
    - Single, abandoned
    - Single, dismantled
    - Single, under construction
  - Tunnel
  - Underpass, overpass
  - Yards
- Roads and related features
  - Bridge
  - Class 1
  - Class 2
  - Class 3
  - Class 4
  - Class 5 (trail)
  - Dead-end road
  - Ferry
  - Interchange
  - Parking area
  - Paved service and rest areas
  - Tunnel
  - Under construction, class 1
  - Underpass, overpass
- Ski lift, tramway, incline railway

Hydrographic features

- Alkali flat
- Aqueduct, conduit, flume, (elevated)
- Aqueduct, flume, and so forth (underground)
- Aqueduct tunnel
- Area subject to controlled inundation
- Area to be submerged
- Breakwater, pier, wharf
- Canal, flume, aqueduct, or perennial ditch
- Canal, intermittent
- Canal lock or sluice gate
- Canal, navigable
- Channel in water area
- Cranberry bog
- Dam, masonry
- Dam with lock
- Ditch, intermittent
- Drydock
- Dry lake or pond
- Falls
- Filtration plant
- Fish hatchery
- Gaging station
- Glacial crevasses
- Glacial or permanent snowfield
- Lake or pond, intermittent
- Lake or pond, perennial
- Lock, shipping canal
- Mangrove
- Marsh or swamp
- Rapids
- Reservoir
- Salt evaporator
- Seawall
- Sewage disposal
- Shoreline
- Siphon
- Spring
- Stream, braided
- Stream, disappearing
- Stream, intermittent
- Stream, perennial
- Stream, unsurveyed perennial
- Submerged marsh or swamp
- Wash
- Watermill
- Water surface elevation
- Water well
- Windmill

framework of geographic information needed by major users (such as the Bureau of the Census) to perform various types of spatial analyses.

DATA STRUCTURE

The digital planimetric data are produced and distributed in the form of digital line graphs. The digital line graph concept is based on graph theory in which a graph can be represented as a set of nodes and links that explicitly records the spatial relationships inherent in the graph.

The digital line graph's topologically structured data file accommodates all of the categories of data (that is, point, line, and area data types) included in table 1. Each distinct major data category (such as transportation and hydrography) is stored as a separate data file in the data base. Details on the digital line graph structure can be found in U.S. Geological Survey Circular 895–C; listings and explanations of the attribute (feature) codes are contained in U.S. Geological Survey Circular 895–G.

This data base, when complete, will contain an immense amount of spatial information. Not only are a large number of features identified and coded, but the level of feature portrayal also is quite detailed. Figure 8, which is a plot of a portion of the road network digitized from the Tallahassee, Florida, 1:100,000-scale map, provides an indication of this detail.

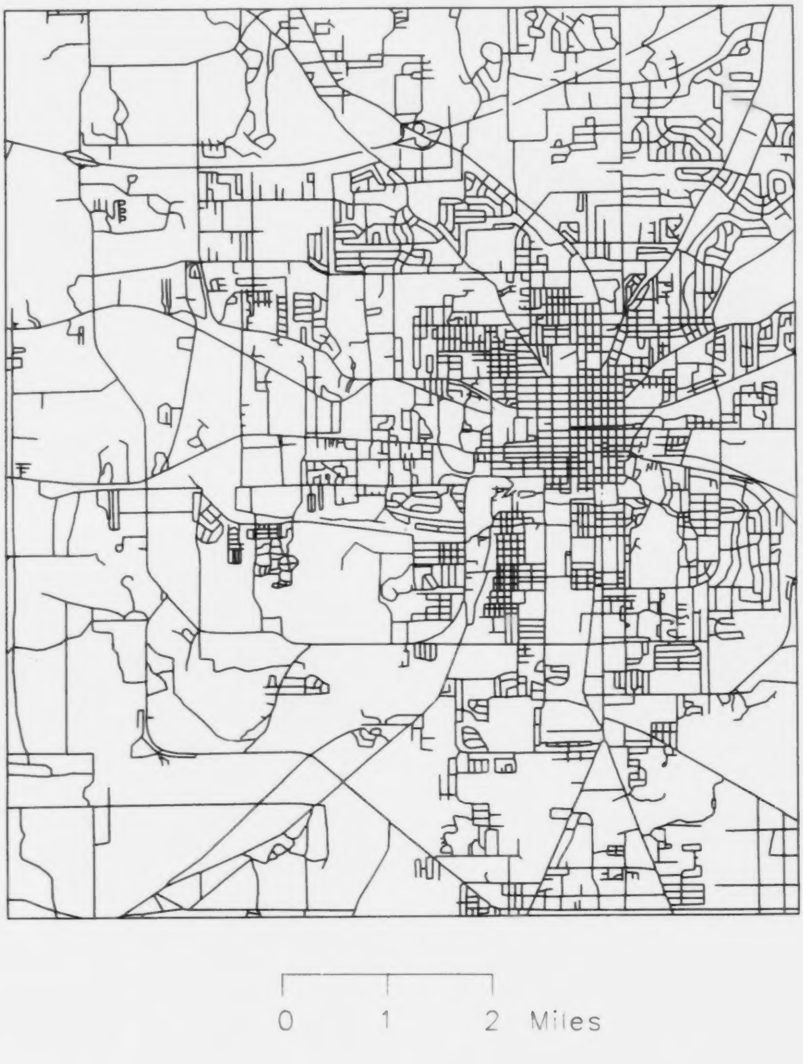


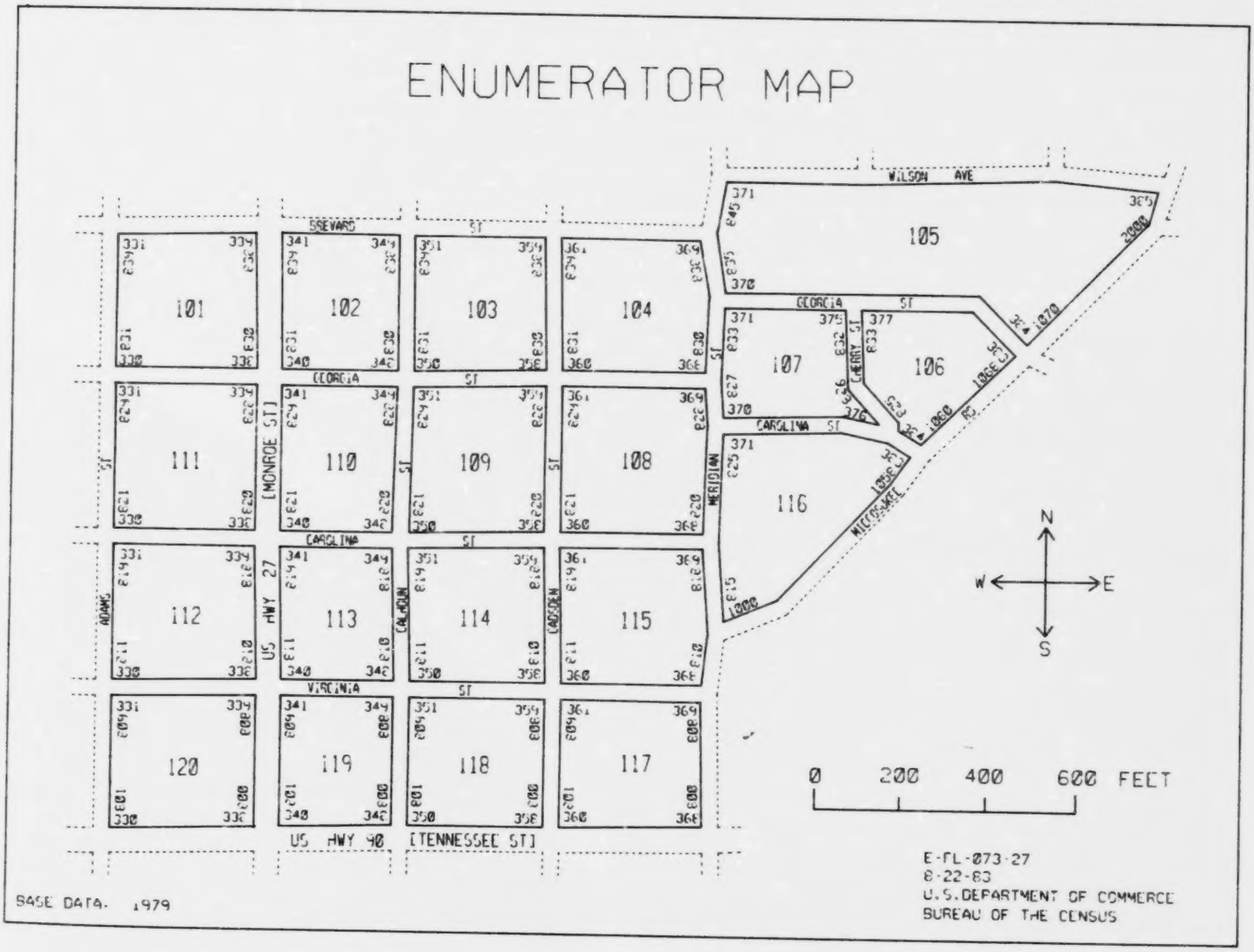
Figure 8. *Plot of digital roads data for portion of Tallahassee, Florida, 1:100,000-scale map.*

ANTICIPATED USES

The U.S. Bureau of the Census has a requirement for digital cartographic data describing roads, railroads, streams, and other geographic features to enable it to automate its geographic support system for the 1990 census. Census is developing its Topologically Integrated Geographic Encoding and Reference (TIGER) System to automate many of the geographically based aspects of data collection, processing, and publication activities associated with a decennial census. According to an article by R. W. Marx in *American Demographics*, "TIGER will store and identify the hierarchical relationships of all geographic areas represented in each census or survey: the 50 states, 3,137 counties, more than 18,000 minor civil divisions or equivalent areas, more than 20,000 incorporated places, and all other areas. . . .TIGER must accurately portray the boundaries of all political and statistical areas recorded in the file, plus the streets, roads, and other map features needed for field operations." The 1:100,000-scale digital cartographic data base will form the cartographic foundation for the TIGER files. One example of a geographic product that Census will produce from the system is shown in figure 9. The Geological Survey and the Bureau of the Census have agreed to work jointly in the production of this data base.

The 1:100,000-scale digital cartographic data base will provide the geographic framework for geographic information systems through the rest of the century. The addition of street names and census-keyed geocodes by Census will allow spatial analysis of vast amounts of socioeconomic data. The Geological Survey is adding information on land ownership and mineral resources to the base categories to form

Figure 9. *Proposed enumerator map as it will be created by the U.S. Bureau of the Census' Topologically Integrated Geographic Encoding and Reference System.*


ENUMERATOR MAP
WILSON AVE
BREVARD ST
GEORGIA ST
CAROLINA ST
VIRGINIA ST
US HWY 90 [TENNESSEE ST]
US HWY 27 [MONROE ST]
ADAMS ST
CALHOUN ST
GADSDEN ST
MERIDIAN ST
CHERRY ST
MICCOSUKEE RD
101
102
103
104
105
106
107
108
109
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111
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8-22-83
U.S. DEPARTMENT OF COMMERCE
BUREAU OF THE CENSUS
BASE DATA. 1979

a data base for resource management decisions on Federal mineral lands. The 1:100,000-scale digital cartographic data base combines the heretofore elusive qualities of sufficient detail, adequate content, and nationwide coverage that will allow, and perhaps foster, the widespread use of spatial analysis methods. Digital dashboard road maps and automated yellow pages based on the information in this data base are two futuristic concepts that could become a reality.

A synergistic effect will be realized through the combination of the 1:100,000-scale data base with digital remote sensing data. The new generation of higher resolution, multispectral remote sensing satellites (Landsat 4 Thematic Mapper, SPOT, and others) are providing detailed data about the Earth's surface. The cartographic data could provide accurate geometric control for the remote sensing data. Networks of linear features (for example, major highways) extant in both sets could allow for better fit of remote sensing data to a cartographic base than is now possible through the use of isolated control tie points. The digital merging of these two types of data could allow new methods of imagery analysis to be developed. Conversely, if the resolution of the remote sensing data is adequate, direct digital update of features in the cartographic data base may be possible.

SUMMARY

The Geological Survey is beginning a program to create a digital cartographic data base containing transportation and hydrographic features from its 1:100,000-scale maps by the end of the decade. The Bureau of the Census is cooperating in the development of this data base and will enhance it through the addition of street names and census geocodes. The existence of this data base will enable the widespread use of geographic information systems for a host of resource-management, area-analysis, and planning activities. Combined with remotely sensed digital data, our ability to study and monitor the Earth's surface will be improved. This data base will not only meet the immediate (1990) needs of the Federal community, but it may well serve as the catalyst for the widespread use of geographic information systems technology in the United States.

Disintegration of the Lower Reach of Columbia Glacier, Alaska, Now Under Way

By Mark F. Meier

The Trans-Alaska Pipeline carries oil from the North Slope of Alaska, where ice problems abound, to Valdez, described as "our northernmost ice-free port." Here the oil is loaded on tankships for delivery to the lower 48 States. At the time the pipeline terminal was built, ice in the shipping lanes of Valdez Arm was encountered rarely and was not considered to be a problem. Now, however, icebergs are seen frequently in Valdez Arm, and, occasionally, tankships have to be diverted or delayed because of ice. These delays can be expensive; oil storage capacity at the terminal is limited, and stoppage of the flow in the pipeline or pumping of the wells can have serious economic consequences. And the iceberg problem is likely to get worse before it gets better.

Why is this happening? It is because the nearby Columbia Glacier is beginning to disintegrate, causing a large increase in the breaking off (calving) of icebergs. This disintegration was, in fact, predicted by U.S. Geological Survey glaciologists in 1980. The prediction followed the development, also by Geological Survey glaciologists, of an understanding of why glaciers that end in the sea behave the way they do.

Most glaciers that end on land advance or retreat slowly in response to fluctuations in climate. Glaciers that end in the sea also may advance or retreat slowly, but sometimes they make extremely rapid and long-continued retreats; for instance, Muir Glacier in Glacier Bay has retreated 25 miles since being mapped by a Geological Survey glaciologist in 1892, while neighboring glaciers have remained stable or even advanced. Even more remarkable, the composite Guyot-Yahtse-Tyndall Glacier, which terminated on the continental shelf of the Gulf of Alaska at the turn of the century, has now retreated 29 miles, creating the present-day Icy Bay, yet the glaciers on either side have remained virtually unchanged.

The cause of these unusual rapid retreats is now known: It is because the speed at which the glacier releases (calves) icebergs depends on the water depth at the terminus (end) of the glacier. The speed of calving is high when a glacier terminates in deep water

The terminus of Columbia Glacier as viewed from Heather Island on August 14, 1984. Note the immense grounded icebergs in the foreground. Mount Columbia (left) and Mount Witherspoon (right) are visible in the background. (Photograph by Mark F. Meier, Water Resources Division, U.S. Geological Survey.)

and is low when a glacier terminates in shallow water. When a glacier ends in shallow water, the rate of ice flow to the terminus can match the rate of ice discharge from the terminus; the glacier is stable. On the other hand, when a glacier ends in deep water, the rate of discharge of icebergs is very high and cannot be matched by ice flow; the glacier is unstable and retreats very rapidly and irreversibly until it again ends in shallow water.

Columbia Glacier, which terminates in the waters of Prince William Sound near Valdez, Alaska, had been stable since first studied in 1899. Survey glaciologists, however, realized in the mid-1970's that it could make a drastic retreat and that the ensuing increase in iceberg discharge might pose a problem to the shipping of oil from the Valdez terminus of the Trans-Alaska Pipeline. By 1980, iceberg calving relations had been quantified, computer models of the glacier's dynamics had been developed, and a prediction had been issued (fig. 1). This prediction stated that disintegration of the lower reach would, in fact, begin in the next few years and that the iceberg discharge would increase to more than six times the 1977 to 1980 level.

Disintegration of Columbia Glacier is now underway. Since 1980, recession, thinning, and iceberg discharge have been accelerating. Never before have scientists been able to observe the beginning of instability and drastic retreat, and observations of this glacier are adding much new information, some of which is surprising and unanticipated; for instance,

- Ice velocity, which had averaged 15 to 23 feet per day at the terminus between 1977 and 1978, rose in 1983 and averaged more than 50 feet per day during winter 1983–84.
- Iceberg calving, which had averaged about 3 million tons per day from 1977 to 1981 and was almost zero in winter, rose to 10 million tons per day during winter 1983–84 and continues at a high rate.
- The rate of retreat has accelerated, from an average of 130 feet per year from 1976 to 1981 to 600 feet per year from 1981 to 1983 to 1,560 feet from 1983 to 1984, referenced to the July 1 position each year (fig. 2). From July to mid-August 1984, retreat measured 16 feet per day averaged over the width; in the center, it was 50 feet

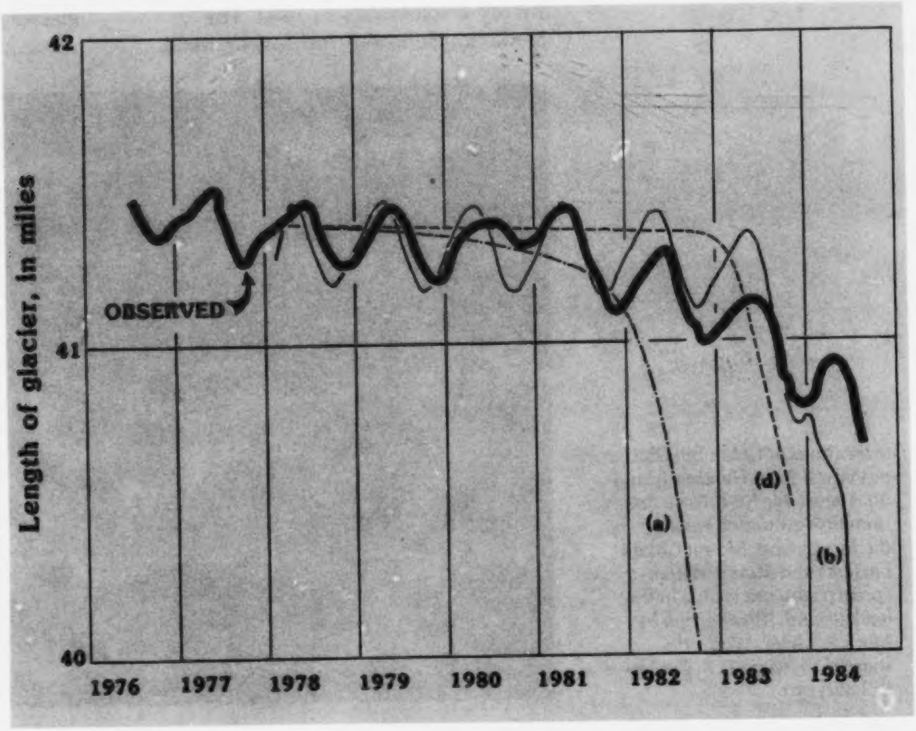
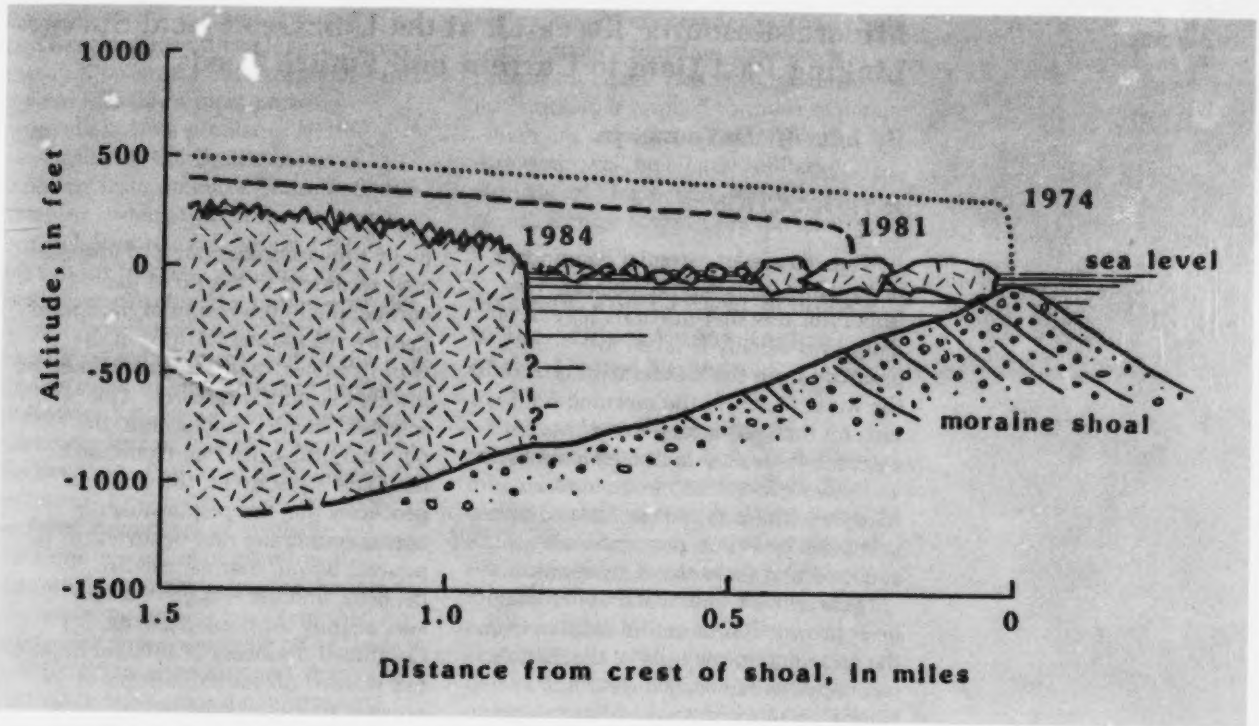


Figure 1. *Changes in the length of Columbia Glacier since 1976. Upward trend represents advance, downward trend represents retreat. Heavy line is observed behavior of the terminus, averaged over the width. Light lines labeled (a), (b), and (d) show predictions using different kinds of numerical models.*



per day in spite of a forward ice flow of 39 feet per day, so the calving in midglacier was averaging 89 lineal feet of glacier ice removed each day. As the glacier is more than 1,000 feet thick at the terminus, this is a huge volume of ice discharged each day.

- The thickness of the lower reach of the glacier decreased 85 feet on the average between 1974 and 1981. During the next 2 years, September 1, 1981, to September 1, 1983, it decreased an additional 100 feet, and the rate of thinning continues to increase. The ice reserves of this glacier are being depleted in an unsuccessful attempt to make up for the ever-increasing loss by iceberg calving.
- Perhaps most unusual was the fact that during February and March 1984, a portion of the glacier "surged" out in front of the rest of the terminus as a floating tongue, and other parts of the terminus appeared to be in a near-floating condition. This situation had not been anticipated, but this is the first time that the beginning of calving disintegration had been subject to close scrutiny by scientists.

With the disintegration of the Columbia Glacier now underway, Geological Survey scientists are monitoring the rate of iceberg discharge with great care. This monitoring is essential because serious economic consequences could result from appreciable delays in the delivery of oil from the Trans-Alaska Pipeline.

Figure 2. *Longitudinal section of the terminus of Columbia Glacier, as of August 1984; the 1974 and the 1981 profiles also are shown. Although the terminus of the glacier has retreated into water more than 900 feet deep, the ice is not floating. Also, large icebergs are grounded against the moraine shoal, trapping other floating ice blocks and delaying their release to navigable waters.*

Mineral-Resource Research at the U.S. Geological Survey—Linking Past Data to Current and Future Needs

By John H. DeYoung, Jr.

INTRODUCTION

Minerals are an essential component of our modern industrial society. The important role that minerals play in our daily lives usually is taken for granted—from the moment we turn on the water faucet in the morning until we turn off the light at night. We use automobiles, refrigerators, telephones, and other necessities of our modern lifestyle without thinking of the complex processes by which raw materials are acquired and these items are made.

These mineral raw materials have been provided in bountiful fashion from the apparent cornucopia of the Earth's resources. In the early days of our Nation's history, deposits of metals and other mineral materials were found in close proximity to the population that used those materials and settlements often were established in areas undertaking mineral development operations. The westward movement of the population brought new mineral discoveries, and, in some cases, the mineral discoveries spurred more movement to the West. As domestic deposits of some minerals were depleted, the United States turned to international trade to satisfy its needs for minerals.

Today, we are dependent, to a significant extent, on foreign sources for at least 20 important mineral commodities—from manganese, an essential ingredient in steelmaking, to cobalt, an indispensable component of high-temperature alloys such as those used in jet engines. Proposals to lessen U.S. mineral-import dependence rely upon solutions that include alternative sources of domestic production, finding new deposits abroad to increase competition in foreign markets, research on substitute materials, and investing in stockpiles to lessen the effect of our import dependence in crisis situations.

Whether or not our mineral raw material needs are satisfied from domestic or foreign sources, the process that moves minerals from the conceptually dimensionless point of undiscovered resources at the tip of the cornucopia to the reality of production that we see issuing forth from the world's mines, quarries, pits, and wells involves scientific research. This scientific inquiry reaches into the physical properties that characterize the Earth's resources, the geologic processes that are responsible for concentrating the rare occurrences of mineral wealth that we call ore deposits, and the ways to explore successfully for these deposits. Continued discovery of mineral deposits has warded off the exhaustion of mineral supplies predicted by some popular writers, who reasoned that the depletion of nonrenewable resources from a fixed number of deposits permited the calculation of a day of reckoning for mineral resources. In the past, however, carefully reasoned estimates of remaining resources of coal, oil, copper, or other commodities later proved to be conservative because of new discoveries.

The discovery stage in the mineral supply process is the result of inquiry driven by the immediate goal of providing information to use in solving *today's* problems. This research usually draws upon knowledge accumulated from *past* scientific investigations. In addition, a plan for research can recognize that solutions to *future* mineral supply problems will be made with today's basic research results and thus can anticipate potential problems. With such a research plan, we shall be ready to solve these problems or to avoid them entirely.

Highlights of fiscal year 1984 mineral-resource research at the U.S. Geological Survey include examples of studies directed towards immediate problems, accumulation and organization of data from past investigations, and studies of basic research questions that will build the analytical tools for tomorrow's exploration and mineral-resource assessment. Current Geological Survey research programs have responded to several of today's most pressing mineral-resource problems: (1) the availability to the United States of minerals from domestic sources, (2) the need for systematic, comprehensive mineral-resource and geologic information for land use planning and mineral exploration, (3) the preservation of past knowledge so that it does not have to be rediscovered, and (4) the development of new tools and methods to explore for, assess, and increase our understanding of mineral resources and the processes that form them. These responses have provided continually updated summaries of available domestic resources of all mineral commodities, descriptions of the mineral resources on Federal land proposed for wilderness preservation or other land-use decisions, summary and storage of current mineral-resource information in accessible data bases, guidance for future research by identification of what we do not know, and the development of innovative methods to provide answers to as yet unknown resource problems. In a 1975 Congressional Research Service report about the U.S. Geological Survey, Dr. Allen Agnew noted that, since its inception, the Geological Survey has maintained scientific eminence and has produced valuable and forward-looking natural-resource programs that have made important contributions to the formulation of the Nation's mineral resource policies. Some of the significant results and current state-of-the-art mineral-resource investigations are described below.

DOMESTIC SOURCES OF MINERAL SUPPLY

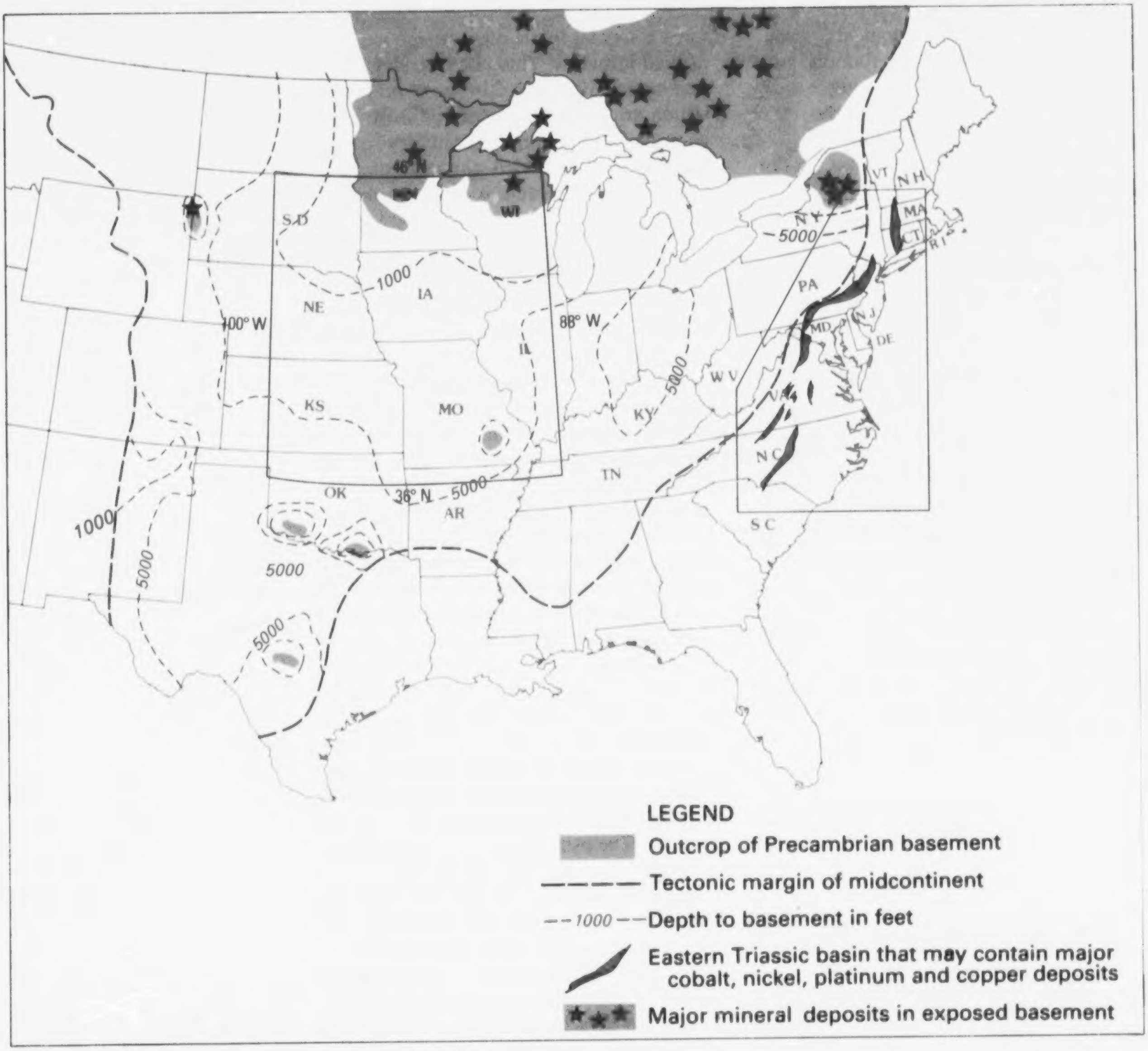
Closer looks at some unconventional geologic environments offer exciting possibilities for new domestic sources of minerals. Three areas currently being studied by the Geological Survey are the midcontinent region, eastern Mesozoic basins, and the offshore areas included in the Exclusive Economic Zone. Investigations in these areas encompass a wide range of mineral-deposit types but have a special focus on strategic and critical minerals. This term, strategic and critical, is applied to those minerals which are essential to our Nation's economic well being and military security and for which domestic or secure foreign sources are not assured.

Strategic and Critical Minerals in the Midcontinent Region of the United States

Because favorable geological conditions for several types of concealed mineral deposits were identified in an earlier Geological Survey study of the Rolla, Missouri, area, a similar mineral-resource study, focussed on a few mineral commodities but encompassing a larger region, was started in fiscal year 1984. An area embracing all or part of 12 States between 36 and 46 degrees north latitude and 88 and 100 degrees west longitude will be studied by the Geological Survey and State agencies using geologic mapping, geochemical sampling, and measurements by geophysical teams (fig. 1).

The development of new concepts and methods for the identification of concealed mineral deposits in heretofore untested, but possibly mineralized, locations has been stimulated by the depletion of mineral resources from deposits discovered near the surface. The midcontinent region is an example of this situation because, until recent times, the only known mineral deposits in that region were those that outcropped. The potential for the occurrence of additional very large and economically significant mineral deposits in the subsurface of this region is excellent. From 1978 through 1982, the State of Missouri accounted for 90 percent of the U.S. mine production of lead, 20 percent of its zinc, and smaller amounts of copper, silver, and cadmium. These metals are produced from vast deposits that are concealed under 800 to 1,200 feet of barren overlying rock.

Historically, mining interest in the midcontinent region has centered on the near-surface sedimentary rocks (limestones and dolomites), which contain deposits of lead and zinc and are called


46° N
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100° W
88° W
36° N
1000
5000
LEGEND
Outcrop of Precambrian basement
Tectonic margin of midcontinent
1000 Depth to basement in feet
Eastern Triassic basin that may contain major cobalt, nickel, platinum and copper deposits
Major mineral deposits in exposed basement

Figure 1. *Areas of study for assessing the strategic and critical mineral potential of the midcontinent and eastern Mesozoic basin regions.*

Mississippi-Valley-type deposits. Recently discovered gold deposits—containing over 16 million ounces of gold in almost 70 million short tons of ore—in Precambrian basement rocks near Hemlo, Ontario, have demonstrated the possible economic importance of the Precambrian rocks that underlie the midcontinent region. These rocks are similar to Precambrian basement rocks in Canada that contain, in addition to gold, major deposits of copper, nickel, lead, and zinc. The Geological Survey's midcontinent mineral-resource investigations will focus on the potential for occurrence of deposits of strategic and critical minerals in the Precambrian basement rocks and in the overlying limestone sedimentary rocks.

New resource possibilities for these overlying rocks have been indicated by recent fluid-inclusion studies and by the consideration of plate tectonic theories. The examination of trapped bubbles of fluid in the hydrothermal, vug-lining dolomite collected from mines, quarries, and drill cores in Missouri, Kansas, Arkansas, and Oklahoma indicates that hot, highly saline fluids moved northward from the Ouachita Mountains. The similar composition of fluid inclusions from many mineral deposits in the region suggests a regional migration of a common mineral-rich fluid. This fluid migration is believed to be related to crustal collision that occurred about 300 million years ago. Research to determine the origin and the location of mineral deposits formed during these ancient events will aid in the discovery of new mineral resources.

Eastern Mesozoic Basins

Mesozoic rift basins, formed between 205 and 240 million years ago, are another potential domestic source of minerals, including nickel, cobalt, and platinum-group elements for which the United States presently depends upon imported supplies. In the Soviet Union, near the city of Norilsk, similar rift basins contain significant deposits of nickel, copper, and platinum metals. Mesozoic basins of this type also are considered to be potential hosts for uranium deposits.

Concurrent with the midcontinent studies, the Geological Survey is investigating 10 Mesozoic rift basins or subbasins that are exposed in a belt that extends from Massachusetts to South Carolina (fig. 1). Many more of these basins are buried onshore beneath coastal-plain sediments and offshore beneath the continental shelf. The goal of these field and laboratory studies is to identify and outline areas that are favorable for the occurrence of base-metal deposits. Descriptions of examples of each type of mineral deposit associated with rift-basin environments are prepared for use as comparative models. The models are important tools for identifying favorable terranes for mineral deposit occurrence.

Exclusive Economic Zone

The Geological Survey continues to investigate the mineral potential of the Exclusive Economic Zone (EEZ) that was declared by President Reagan on March 10, 1983. The EEZ is the offshore area that extends 200 nautical miles beyond he shorelines of the United States and ts territories and possessions. Oil and gas have been produced from portions of the United States EEZ, but the mineral resources of this large area (3.9 billion acres compared with the 2.3 billion acres of total onshore area for the United States) are virtually unknown. Three types of offshore mineral deposits that are the subject of current investigations are marine heavy-mineral placer deposits, cobalt-bearing manganese crusts and nodules, and polymetallic sulfides.

Marine Heavy-Mineral Placer Deposits

Geological Survey researchers are examining the continental shelves of the United States for possible sources of heavy minerals, which are concentrated in placer sand deposits by the action of water currents, waves, and winds. Titanium minerals, monazite, zircon, cassiterite, gold, sillimanite, kyanite, andalusite, garnet, staurolite, corundum, phosphorite, and other heavy minerals have been identified or indicated on the Atlantic Continental Shelf, where initial investigations are taking place. The mineralogy and chemistry of new and archived mineral sand samples from the Atlantic offshore are being studied using methods that represent significant improvements in the tools of reconnaissance and in methods of sample preparation and analysis. Results of preliminary studies have shown high concentrations of heavy minerals in an offshore area of Virginia where onshore deposits contain relatively low heavy-mineral concentrations. These results, although limited to one area of the Atlantic Continental Shelf, indicate that exploration philosophies linking the best offshore target areas with high onshore heavy-mineral concentrations may not be as reliable as previously thought.

Cobalt-Bearing Manganese Crusts and Nodules

Recent studies suggest that cobalt-bearing manganese crusts on the flanks of seamounts and oceanic islands in the central Pacific Ocean may represent a significant mineral resource. Cobalt content ranges from about 0.4 percent for the deeper crusts to 1.2 percent on seamount tops shallower than about 7,500 feet. Some crust material dredged from a seamount about 160 miles northwest of the U.S. territorial possessions of Palmyra Atoll and Kingman Reef contained 2.5 percent cobalt, more than twice the concentration indicated by earlier studies.

Polymetallic Sulfides

Deposits of polymetallic sulfides have received much publicity in such journals as the *National Geographic*, where photographs from the research submersible *Alvin* have been printed. Studies by the Geological Survey of sulfide deposits along spreading centers, such as the Juan de Fuca Ridge off the coast of Washington State, are designed to determine how these deposits are forming and to assess the mineral resources of these areas. This information will help scientists to understand the environments of deposition of similar onshore deposits and aid them in locating additional terranes that are favorable for the occurrence of sulfide-type deposits.

Regional Mineral-Resource Studies for Land Use Planning

New understanding of the Nation's mineral endowment has been gained from the Geological Survey's systematic geologic and mineral-resource studies of 1:250,000-scale quadrangles (an area ranging from 5,000 to 8,000 square miles) and of mineral-resource surveys done with the U.S. Bureau of Mines under legislative mandate in those areas included or proposed for inclusion in the National Wilderness Preservation System.

The systematic quadrangle studies are carried out under two programs: the Conterminous United States Mineral Assessment Program (CUSMAP) for the 48 conterminous States and the Alaskan Mineral Resource Assessment Program (AMRAP) for Alaska. These two programs are providing a modern, systematic mineral-resource assessment of areas that have indications of mineral resources, especially for strategic and critical minerals. Mineral resources of the quadrangles are assessed by using data gathered during coordinated efforts of teams of scientists doing geologic mapping, geochemical sampling of rocks and stream sediments, and analysis of measurements from geophysical surveys and satellite imagery. By fiscal year 1984, 175,000 square miles had been assessed under AMRAP, and 80,000 square miles under CUSMAP. Present plans call for approximately 600,000 square miles of Alaskan lands to be assessed by the year 2000 and for almost a million square miles to be assessed in the conterminous United States during the next several decades.

The responsibility of the Geological Survey and the U.S. Bureau of Mines to assess the mineral resources of certain public lands that are administered by the Bureau of Land Management and the Forest Service is a provision of the Wilderness Act (Public Law 88–577, September 3, 1964) and of subsequent related legislation. Under the Federal Land Policy and Management Act of 1976, the Geological Survey and Bureau of Mines have undertaken mineral surveys of Bureau of Land Management-administered lands for which a preliminary determination of wilderness suitability has been made. The Bureau of Land Management has found that 23.2 million acres deserve further study for wilderness consideration. The mineral resources of 12 Indian reservations also are being assessed by the Geological Survey for the Bureau of Indian Affairs.

Mineral-resource assessments from the CUSMAP, AMRAP, and public land studies can be used along with information about other possible land uses (timber, agriculture, grazing, recreation, and various types of development) to plan land uses that are in keeping with the Nation's interests. In addition, the Geological Survey has, in the course of these assessment studies, developed new techniques and methods of resource assessment which are applicable to public and private lands and which provide a practical approach to the assessment of the mineral endowment of the national domain.

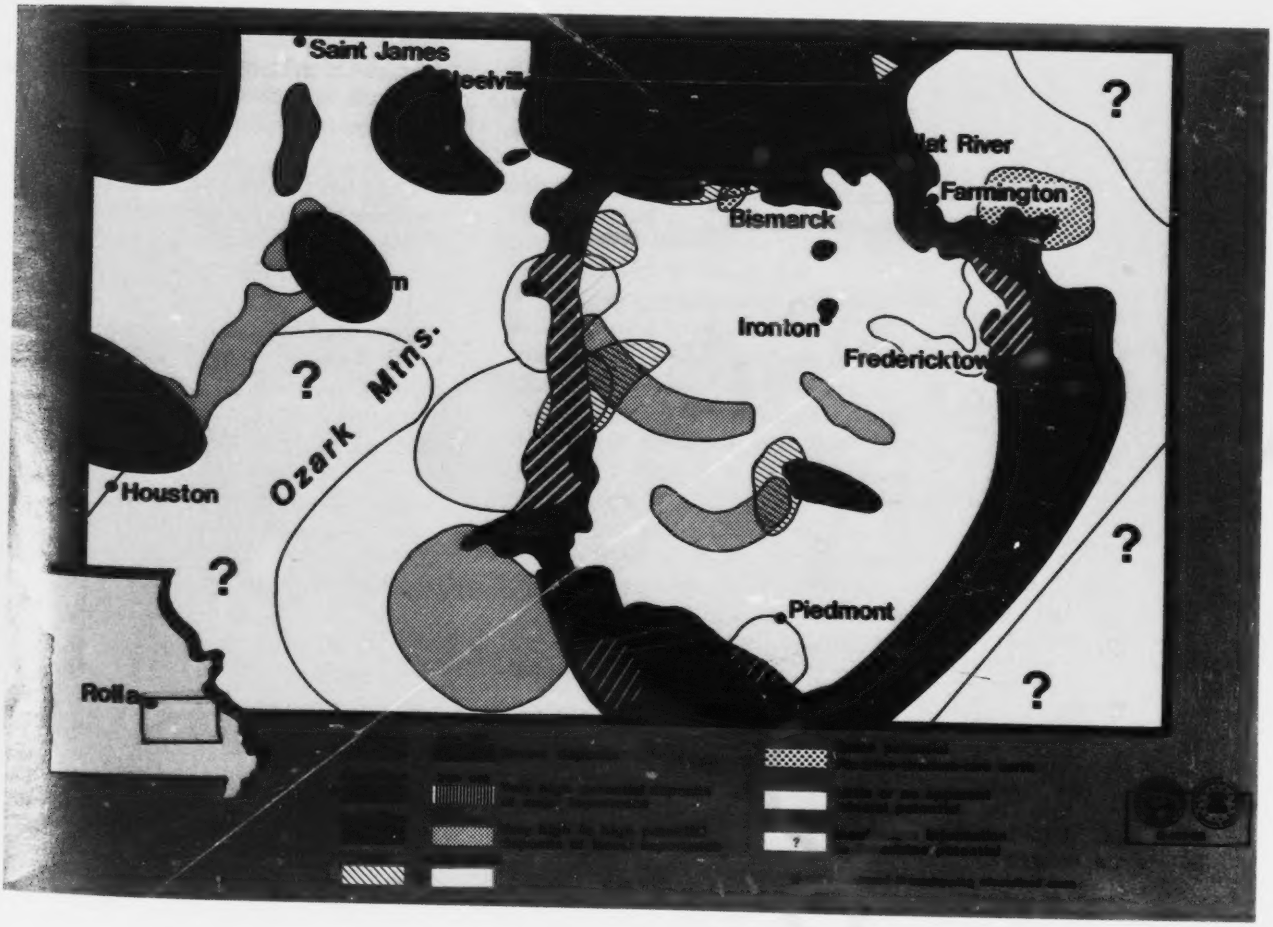
Some recent highlights of regional mineral-resource assessment studies are the completion of the Rolla, Missouri, quadrangle under CUSMAP and the publication of a summary of the public lands mineral-resource studies done over the last 20 years under the Wilderness Act mandate.

Mineral Resources of the Rolla, Missouri, Quadrangle

The Rolla quadrangle was chosen as one of the first quadrangles for study under CUSMAP because it contains known mineral occurrences and high potential for additional undiscovered occurrences of important minerals. The quadrangle (an area of about 8,000 square miles) includes most of the southeast Missouri lead-mining district, an area which contains the largest lead reserves in the world (fig. 2). The important mineral deposits of this major district occur in geologic formations that extend beneath the surface for hundreds of miles to the north and west of this area. The Rolla quadrangle is thus an excellent field laboratory for the development of mineral-resource-assessment methods that can be used throughout regions where similar geologic environments suggest the existence of mineral deposits like those that occur in the Rolla quadrangle. The studies in the Rolla quadrangle were done in cooperation with the Missouri Division of Geology and Land Survey.

During the Rolla study, an innovative geochemical technique was developed that has significant possibilities for subsurface exploration throughout the midcontinent and similar geologic regions. This technique is based on the chemical and mineralogical analysis of whole-rock and insoluble residue samples of drill core in the sample library of the Missouri Division of Geology and Land Survey. The drill holes selected for the analysis are not industry proprietary, do not intersect economically significant mineralized ground, and, in most cases, are not located in the Old Lead Belt, the Viburnum Trend, or other known ore-bearing localities. The whole-rock samples from the drill core were used to determine an intrinsic suite of trace elements that reflects the types of rocks in the geologic formations in the drill cores—dolomites, limestones, shales,

Figure 2. *Mineral-resource assessment of the Rolla 2-degree quadrangle, Missouri.*



and siltstones. An introduced (or epigenetic) suite of trace elements in some samples also is present. Concentrations of the introduced-suite elements are commonly very low in the whole-rock samples, but they are enhanced many times in the insoluble residue samples. The introduced suite of metals and their relative abundances in the suite were found to be the same as those found in ores of the southeast Missouri lead-mining district. By "mapping" relative metal abundances as well as other relationships of the introduced metal suite and correlating this information with certain characteristics of the subsurface stratigraphy, the scientists discovered that the probable extent of the zone that contains base-metal deposits is significantly larger than originally thought. These results were used by the team of Geological Survey and Missouri Division of Geology and Land Survey scientists to identify three areas in the Rolla quadrangle that are highly favorable for the existence of base-metal resources. The team also estimated the quantity of lead, zinc, copper, silver, nickel, and cobalt resources in the quadrangle; for example, the cobalt present in deposits in the quadrangle is estimated to be as much as 30 million to 55 million pounds—equivalent to 2 or 3 years' U.S. consumption of this strategic metal.

Mineral Resources and Public Lands

A major summary of wilderness mineral potential was published in 1984. U.S. Geological Survey Professional Paper 1300, titled *Assessment of Mineral-Resource Potential in U.S. Forest Service Lands Studied, 1964–1984*, a two-volume, 1,183-page work, brings together the results of a 20-year program that was completed by the U.S. Geological Survey and the U.S. Bureau of Mines under the provisions of the Wilderness Act of 1964 and subsequent related legislation. The report summarizes our current knowledge of known mineral and energy resources and of the potential for the occurrence of undiscovered mineral and energy resources in about 45 million acres of Federal lands. This acreage is distributed in about 800 individual areas, chiefly in national forests (fig. 3).

About two-thirds of the areas studied contain zones favorable for the occurrence of one or more mineral commodities that include base and precious metals, strategic and critical minerals, and energy resources. Construction materials are plentiful in most areas.

Land use planners seek a quantitative estimate of mineral resources so that

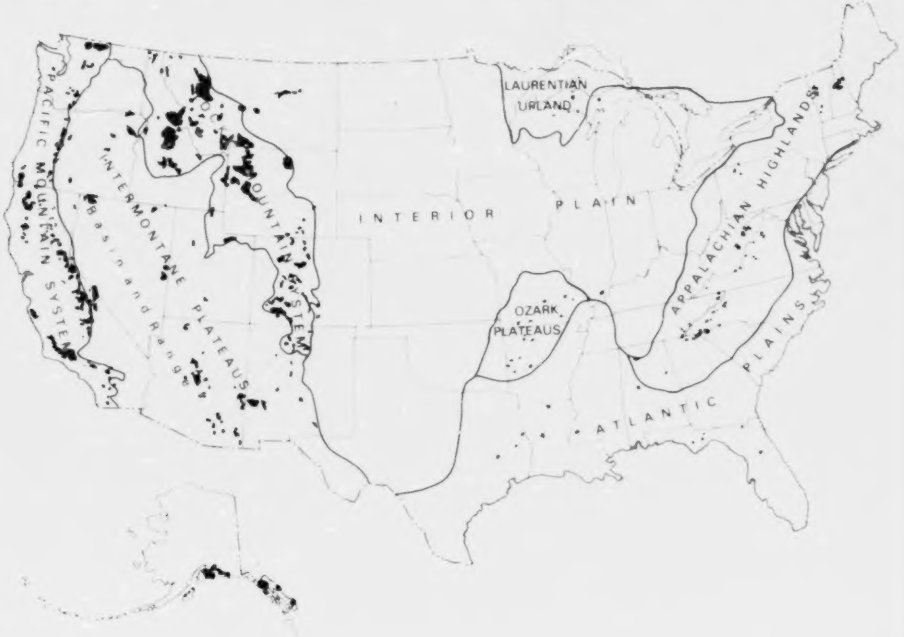


Figure 3. *Distribution of U.S. Forest Service wilderness lands studied from 1964 to 1984 (from U.S. Geological Survey Professional Paper 1300).*

the mineral-resource value of an area can be compared with the estimated values of competing land use possibilities. The development and application of quantitative regional resource-assessment techniques from AMRAP and CUSMAP are being done at the same time that the 20-year study of wilderness areas was being completed. The publication of Professional Paper 1300 presented a summary of subjective evaluations for each area studied and references to site-specific information about the mineral resources of designated wilderness, roadless, or study areas.

In fiscal year 1984, several Geological Survey scientists tested a method for obtaining quantitative estimates of mineral-resource value by using computer simulation techniques, grade-tonnage models of mineral deposits, and the results or referenced studies presented in Professional Paper 1300. The quantitative estimates, although limited to undiscovered resources of selected mineral deposit types in areas of California, Nevada, Oregon, and Washington, are a landmark result for subsequent debate on how to resolve land use conflicts.

ACCESSIBLE INFORMATION BASES—A FOUNDATION FOR BETTER UNDERSTANDING OF MINERAL RESOURCES

To maintain the information bases essential to the proper management of the Nation's mineral-resource position, the Geological Survey continually updates its files of minerals information. This includes information on commodities such as cobalt, chromium, and manganese that are strategic to our national defense but also includes information on construction materials—sand, gravel, building stone, and materials for cement manufacture—and phosphate rock, potash, and other materials used in fertilizers. Not only are these "nonstrategic" materials absolutely necessary to maintain our modern standard of living, but they also have a role in national security. One might ponder the relative importance of cobalt in a jet engine, the crushed stone in the runway, and the agricultural products that sustain the pilot. The United States does not depend on imports for these "nonstrategic" materials, but the scarcity of exploitable sand and gravel deposits near many cities where industrial and residential developments have covered prime deposits points out the need for information on the location, quantity, and quality of mineral deposits.

Information about mineral deposits, occurrences, and related geologic features is obtained by several types of field and laboratory research on mineral resources. Examples include regional and topical mapping projects in the United States and other countries, some of which are done in cooperation with earth science agencies of State governments or foreign countries.

In order that maximum benefit is obtainable from this massive stockpile of mineral-resource data, the Geological Survey maintains the Mineral Resources Data System (MRDS) and the International Strategic Minerals Inventory (ISMI). Some of the plethora of information that is obtained from many diverse research activities is disseminated in a large number of Geological Survey publications, outside journals, and professional meetings; other information is confined to internal reports and files. Through the MRDS, some of this information is organized in a mineral deposit file so that researchers can request information by the geographic location, mineral commodity, or other attribute of the mineral information they seek.

By the nature of the diverse sources from which data are gathered for MRDS, coverage of regions or commodities is not uniform. To improve the comprehensiveness and comparability of data on major mineral deposits, the Geological Survey, along with several other countries, started the ISMI. Progress and activities of MRDS and ISMI during 1984 are described below.

Mineral Resources Data System

This system was started in 1972 as the Computerized Resource Information Bank (CRIB). The Mineral Resources Data

System (MRDS) evolved from the CRIB to become the primary storage system for descriptive and archived historical mineral data for domestic and international deposits.

It is now a major reference tool for Federal, State, and mineral industry scientists who seek information on commodity locations and associated geoscience data. New mineral data are received and entered into the system from a wide range of technical reporters, including Geological Survey regional and commodity specialists. All data in the MRDS are organized into records; each record represents a single mine, mineral occurrence, district, or region. The master file now contains over 64,000 records of mineral deposits and occurrences in the United States and more than 5,300 records for other countries. As the need for rapid access to comprehensive mineral data grows and many pressing mineral policy decisions are being made, the MRDS is being refined and streamlined to handle national and international needs.

International Strategic Minerals Inventory

The easily accessible mineral information stored in the MRDS requires a complementary, summary inventory to complete our present-day knowledge of domestic and international strategic and critical mineral resources and supplies. To satisfy this need, the International Strategic Minerals Inventory (ISMI) was initiated on the premise that, for many mineral commodities, a large proportion of current and near-future production (as much as 90–95 percent) is or will be from a relatively few major deposits and that good information on production, reserves, and identified resources of those major deposits will improve the basis for sound mineral policy decisions. The ISMI also is based on the realization that many industrialized countries maintain extensive global mineral commodity files and that a cooperative program with these countries would avoid a great deal of duplication of effort and greatly improve the quality and amount of information available to each country. The ISMI is supported by mineral-resource agencies of the United States, Canada, West Germany, South Africa, Australia, and the United Kingdom, with the goals of gathering, analyzing, and publishing information on major deposits of selected mineral commodities. A working group made up of representatives of the agencies of participating countries meets on a regular basis, and a continuing compilation of deposit records of selected commodities is underway. The summary commodity reports for manganese, chromium, and phosphate were published in fiscal year 1984 as Geological Survey Circulars 930–A, 930–B, and 930–C. Compilations of data and summary reports for seven additional commodities—nickel, cobalt, graphite, vanadium, titanium, tungsten, and the platinum-group elements—are being prepared.

NEW CONCEPTS FOR MINERAL EXPLORATION AND ASSESSMENT

Basic research that increases our understanding of the descriptive characteristics of mineral deposits and the genetic processes by which they form is the foundation for continued advances in mineral exploration and mineral-resource assessment. Geological Survey research on the fundamentals of mineral resources includes field and laboratory studies of the geologic aspects of economic minerals, modeling studies of mineral-deposit systems, and geochemical and geophysical traits of hidden deposits.

Some types of field and laboratory studies that will have future applications in mineral exploration are geochemical investigations, such as the importance of the role of organic matter in the formation of ore deposits, and geophysical research, such as the development of a new geophysical instrument, called the "Co-Axial Loop, Extra-Low-Frequency Electromagnetic Sounder." This device can detect some sulfide mineral deposits at depths of more than one-half mile without interference from electrical conductors such as fences and electric powerlines.

Included in modelling studies is an emphasis by a large number of Geological Survey geologists with field mapping and other research experience in various types of mineral deposits to record systematically the chemical and mineralogical characteristics and to ecipher the geologic environments of rmation of many types of mineral eposits. Over 60 such models have een constructed; new models are being repared, and existing models are being efined with new information. These escriptive mineral-deposit models and ssociated quantitative estimates of the ize (tons and grades) and abundance of eposits gives the economic geologist roader knowledge to apply to resource-assessment problems. Comprehensive, consistent information about types of mineral deposits also is needed as input to an analysis system that was completed by Stanford Research Institute in 1980 under Geological Survey sponsorship. This study applied artifical intelligence, the area of computer science concerned with computational methods for tasks involving reasoning and perception, to questions of prospect evaluation, regional resource evaluation, and drilling site selection. A microcomputer-based version of this system, designated "muPROSPECTOR," recently has been developed to aid geologists in mineral-resource assessment. This year, the system was used to assess mineral resources in several geologic terranes of the Sherbrooke-Lewiston 2-degree quadrangle in New England as part of CUSMAP.

Exciting new examples of these types of research that were of particular interest in fiscal year 1984 are paleothermal anomalies and models of disseminated gold deposits. Paleothermal studies, using fluid inclusions, fission tracks, and maturation of organic material, gave new clues that will help in locating concealed mineral deposits. Disseminated gold deposits recently have become the largest source of U.S. gold production and were major targets of 1984 industry exploration efforts in the United States.

Detection of Paleothermal Anomalies

Heat plays a role in the formation of some mineral deposits and, at the same time, causes physical and chemical changes in rocks that surround the deposits. The region around a deposit may contain a subtle record of past temperatures that were higher than those associated with the surrounding rocks. This region, in which the rocks may have been heated millions of years ago, is called a paleothermal anomaly (fig. 4*A*) and is analogous to the visible alteration halo sought during traditional mineral exploration. To detect paleothermal anomalies, geologists have studied several geologic features that retain a record of past temperatures. Geological Survey researchers have been instrumental in the development and application of three promising techniques for the detection of paleothermal anomalies: fluid-inclusion studies, fission-track analysis, and organic maturation indices.

Fluid inclusions are small amounts of fluid that were trapped within mineral grains during crystallization or recrystallization (fig. 4*B*). These small (0.001- to 0.01-millimeter) inclusions may contain separate liquid and vapor (bubble) phases as a result of cooling but can be reheated in the laboratory to determine the minimum temperature of the fluid at the time it was entrapped. Studies of fluid inclusions have been used for over a century to determine the temperature of mineral deposits at the time of their formation, but, recently, they have come into wider use in the search for paleothermal anomalies associated with ore deposits. Fluid inclusions provide information about the composition, pressure, and flow direction of mineralizing fluids. They record the paleothermal anomaly well beyond the zone of visibly altered rock through subtle differences in temperature and fluid composition relative to those of the fluid inclusions in the surrounding rock.

Fission-track dating is one of the newer tools used to identify paleothermal anomalies. Fission tracks are small paths of radiation damage caused by the spontaneous fission of uranium in some minerals (fig. 4*C*). The number of tracks present in a mineral crystal is proportional to uranium content and to the length of time since crystallization. These tracks can be partly to completely

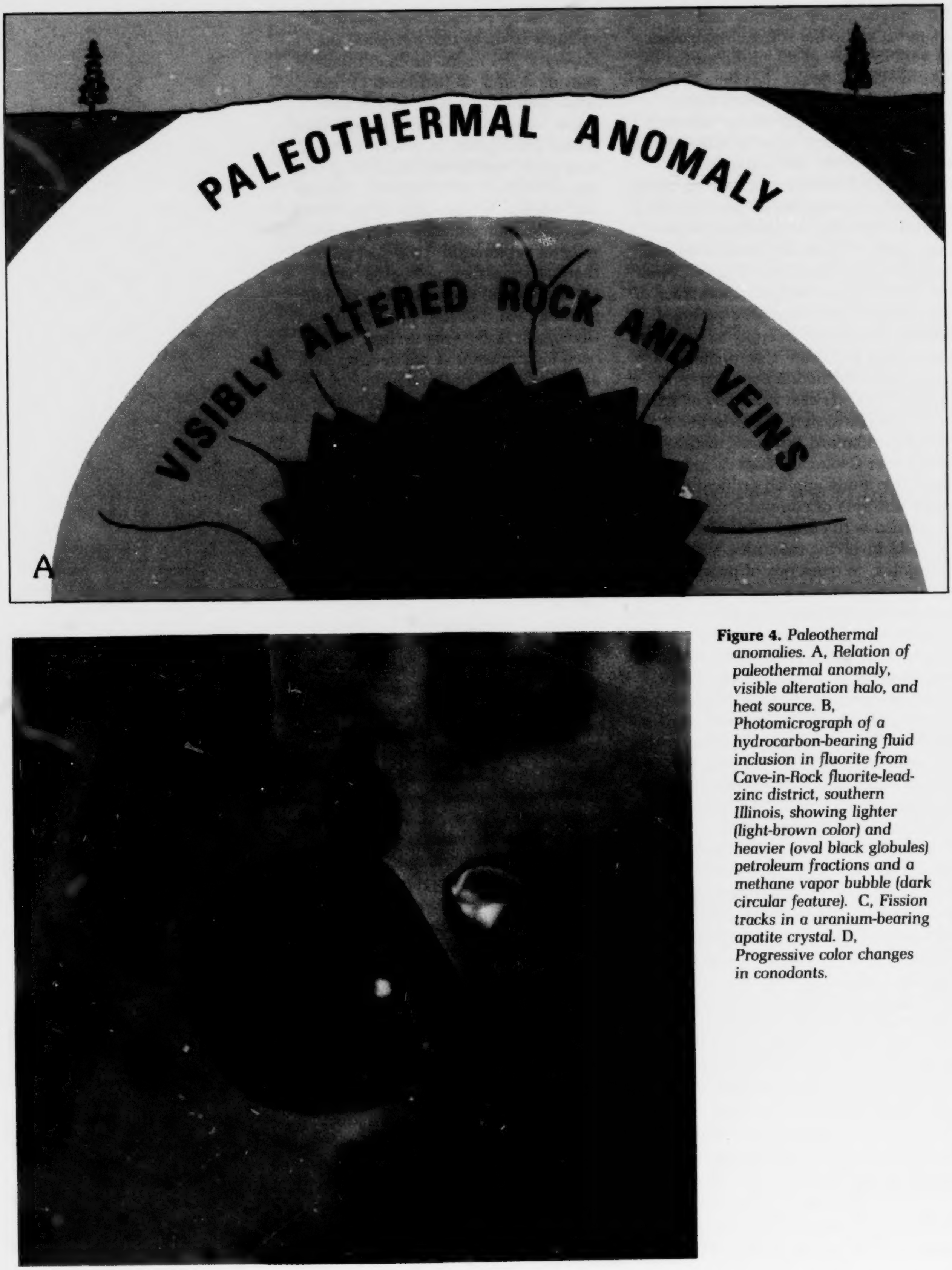
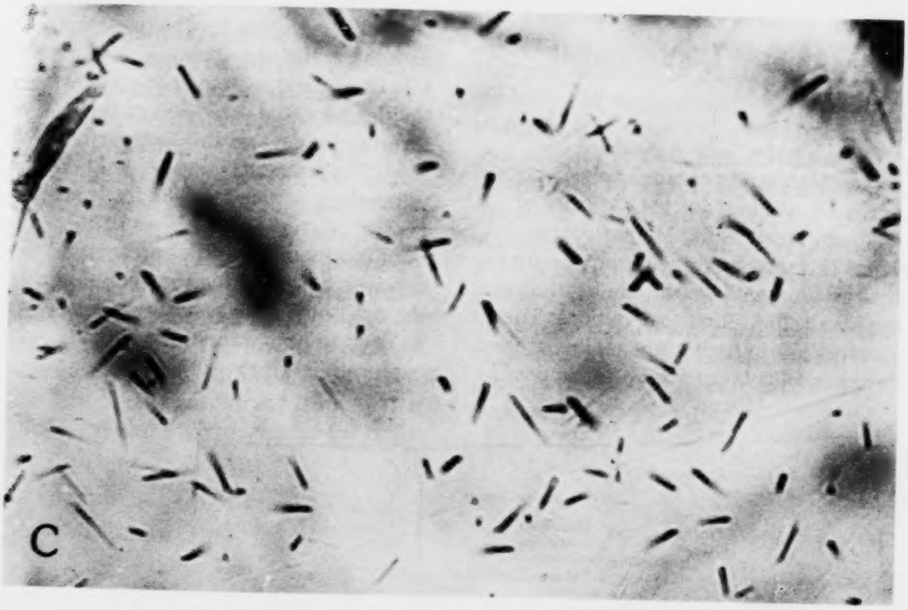
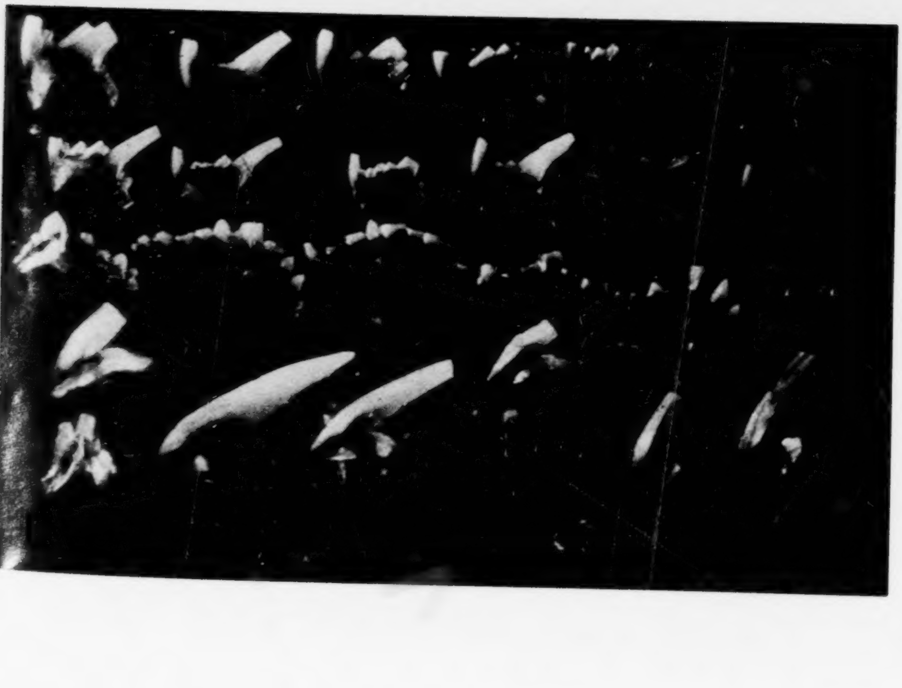

PALEOTHERMAL ANOMALY
VISIBLY ALTERED ROCK AND VEINS
A

Figure 4. Paleothermal anomalies. A, Relation of paleothermal anomaly, visible alteration halo, and heat source. B, Photomicrograph of a hydrocarbon-bearing fluid inclusion in fluorite from Cave-in-Rock fluorite-lead-zinc district, southern Illinois, showing lighter (light-brown color) and heavier (oval black globules) petroleum fractions and a methane vapor bubble (dark circular feature). C, Fission tracks in a uranium-bearing apatite crystal. D, Progressive color changes in conodonts.

annealed, or erased, by reheating. Because different minerals anneal at different rates, scientists can use thermally sensitive minerals, like apatite, which anneals at 105 degrees Celsius, to record a heating event farthest from the heat source. Fission tracks from several samples can be used to determine the direction of the thermal gradient. A recent Geological Survey study demonstrated that a major million-year-old paleothermal anomaly was present east of the old mining camp Rico, Colorado. This anomaly is believed to be related to a concealed igneous rock mass associated with mineralization at the mining camp. The heat source can be sensed more than 3 miles away in rocks that are not changed visibly by using the apatite-derived paleothermal data.

Organic material is also a sensitive recorder of thermal events. Conodonts, the microscopic hard parts of certain marine worms (fig. 4*D*), exhibit a systematic color change as they are heated through the temperature range of about 60 degrees to 550 degrees Celsius. This conodont color alteration index, which has been used for regional

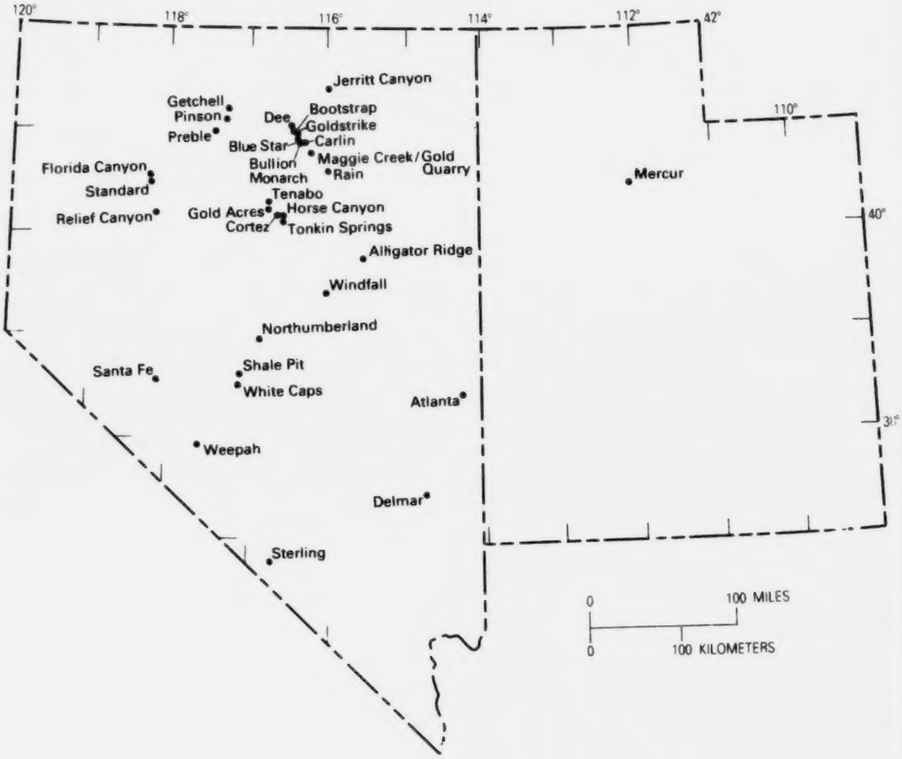




studies of hydrocarbon generation and preservation, is being tested as a paleothermal measure for mineral exploration. Solid organic matter that is dispersed in rocks matures as a function of time to become a glassy, coallike substance called vitrinite. Increased reflectance, as measured by microscope studies, indicates increased maturation. Vitrinite reflectance is applicable to rocks of a wider geologic time span than the conodont index and also is being applied to the search for paleothermal anomalies.

Disseminated Gold-Deposit Models

Disseminated gold deposits in sedimentary and volcanic rocks currently account for the majority of gold produced in the United States. Total U.S. reserves (identified resources that are currently economic to produce) are about 20 million troy ounces. These reserves are in high-tonnage, low-grade deposits—attributes which make possible the use of relatively inexpensive bulk-mining techniques. The majority of known disseminated gold deposits in the United States are located in Nevada and Utah (fig. 5). Gold occurs in the deposits as micrometer-sized particles generally disseminated in either silty to sandy, organic-rich dolomites and limestones or in organic-rich limey shales. The origin and many geologic characteristics of these deposits are not well understood. The Geological Survey currently is conducting research to determine the zonal alteration patterns of these deposits, their geochemical and geophysical characteristics, regional and local structural controls for the ore-forming processes, the age of mineralization, the role of organic matter in the origin of the deposits, the evolution of the ore-forming fluids, and the source of the gold. The research includes study of the mineralogy of the deposits to determine genetic relations and age and study of the fluid inclusions in quartz within the deposits to determine the evolution of the ore fluids. The resulting model can be used to help industry in its exploration efforts.



120°
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Maggie Creek/Gold Quarry
Rain
Florida Canyon
Standard
Relief Canyon
Tenabo
Gold Acres
Horse Canyon
Cortez
Tonkin Springs
Alligator Ridge
Windfall
Northumberland
Santa Fe
Shale Pit
White Caps
Atlanta
Weepah
Delmar
Sterling
Mercur
0
100 MILES
0
100 KILOMETERS

Figure 5. *Disseminated gold deposits in Nevada and Utah.*

CONCLUSIONS

The examples described here demonstrate the Geological Survey's commitment to research that addresses several objectives. Tied closely to this research is an acute awareness of the need for exchange of information. This exchange is accomplished by publication and presentation of results and by cooperative programs with other research groups. Results of completed studies are available for use; reports about ongoing research activities encourage assistance by and suggestions from others.

A new annual forum for the dissemination of Geological Survey research results and information about current research activities is to be held in Denver in February 1985. The first annual McKelvey Forum on Mineral and Energy Resources is titled *USGS Research on Mineral Resources—1985*. The subject matter of the forum will alternate yearly between research on mineral resources and research on energy resources. The forum, which honors Vincent E. McKelvey, Director of the U.S. Geological Survey from 1971 to 1978, provides an opportunity for oral presentations, poster sessions, and laboratory tours that will augment communication among scientists from the Geological Survey, industry, and academic institutions. Directing all sectors of the Nation's scientific strength towards discussion of the multifaceted Geological Survey research effort on mineral resources will help maintain a research agenda that is responsive to present problems, draws on a past record of scientific achievement, and plans ahead for future demands for mineral-resource information.

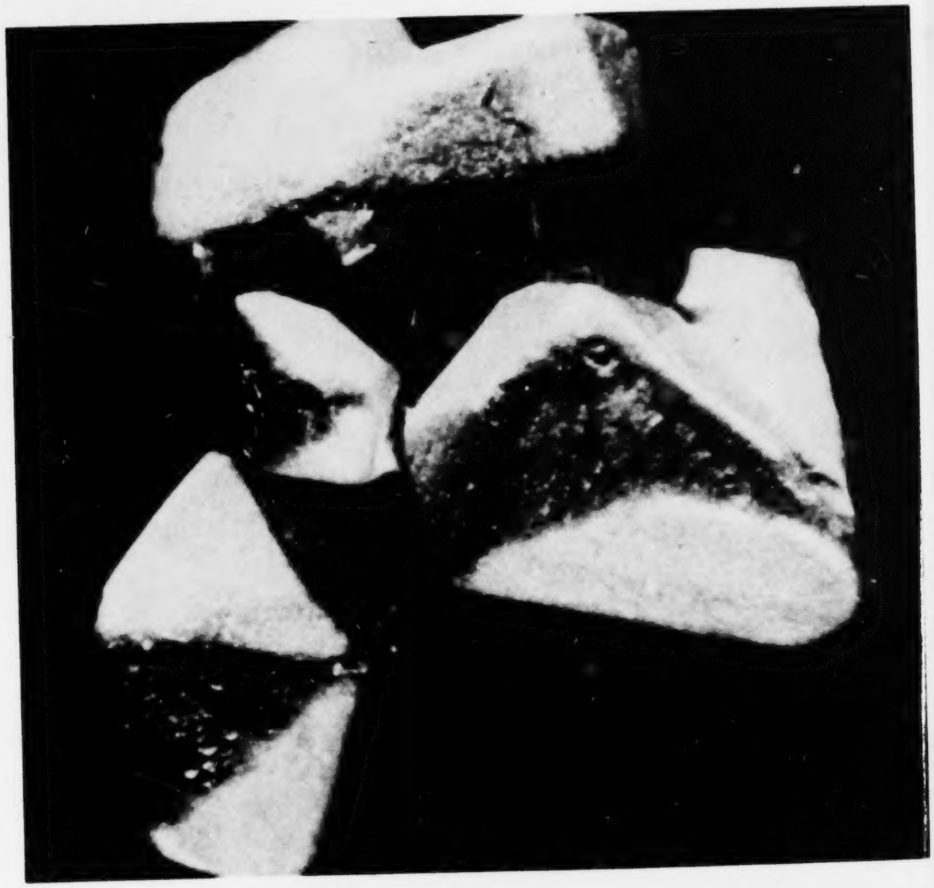
Geological Survey research on mineral resources includes programs that are focussed on present national problems of maintaining the availability of reasonably priced mineral supplies and of using today's mineral-resource information to set tomorrow's land-use priorities. Accessible systems for storage and organization of information from past studies are essential for efficient research. Continued strong, basic research in fundamental aspects of geological science is essential to provide the tools to solve tomorrow's problems.

Significant Accomplishments of Research Programs: 1984

This chapter presents a selected number of U.S. Geological Survey research accomplishments for 1984. More complete discussions of the investigations summarized here are available in other chapters of the *Yearbook* and in other Geological Survey publications on specific topics.

MINERAL-RESOURCE SURVEYS

- New isotopic dating research, chemical analyses, and structural studies have shown that gold veins in the Chugach Range, Prince William Sound region, southern Alaska, formed at the same time that the collision of large blocks of oceanic crust was forming what is now Alaska. The heating caused by the collisions, and the resulting formation of granitic magma, provided water-rich fluids that leached gold and other elements from the host rocks and then deposited them in fractures that now form the gold-bearing veins.
- Fluid-inclusion, isotope, and geochemical studies demonstrated that the silver- and base-metal veins of the Coeur d'Alene district of northern Idaho were formed from metamorphic fluids produced during late Precambrian metamorphism of rocks of the Belt Supergroup. The fluids leached the metals from the typical Belt rocks and deposited them in fractures in the intensely and complexly deformed sections of the Belt rocks.
- A study of the nitrate deposits in the region of Death Valley, California,



Gold crystals, about 1 mm in diameter, from a placer deposit near Sacramento, California.

The Carlin Mine, northeastern Nevada, one of the largest disseminated gold mines in the United States.

shows them to be analogous to the famed Chilean nitrate deposits, the major sources of nitrate for fertilizer and explosives for the 100 years before World War II. The deposits in California consist of wind-transported saline material that accumulated in near-surface layers in the so-called clay hills, which consist of relatively impervious montmorillonite-rich lake beds up to 63 million years old. These deposits do not contain exploitable resources of nitrate, but they do provide a new insight on the mechanisms of accumulation of saline minerals in deserts.

- Geochemical studies of rhyolitic ash-flow tuffs in southern Bolivia, carried out by the Geological Survey in cooperation with the National Geological Survey (GEOBOL) and National Mining Company (COMIBOL) of Bolivia, reveal anomalously high values of tin and lithium in some tuff units. The high tin values indicate that source magmas were enriched in tin and that tin mineralization did not end necessarily before eruption of these rocks as had been assumed previously. It is now believed that tin deposits may be associated with buried intrusive bodies within the volcanic complex. Also, the high lithium values indicate that these rocks are now the major source of lithium found in the widespread and abundant lithium-rich brines in salt pans of this region.
- Previous studies have shown that, during fractional crystallization of silicates from tholeiitic magmas, the residual liquids are depleted greatly in nickel, depleted slightly in cobalt, and enriched in copper. Tholeiitic suites from pre-Triassic rocks that illustrate this fractionation trend (Palisades sill, New Jersey, Dillsburg intrusion, Pennsylvania, Great Lake sheet, Tasmania, and Aloe lava lake, Hawaii) show an increase of copper with a decreasing nickel-

cobalt ratio (trend 1). New data on tholeiitic dikes and flows in Triassic-Jurassic basins in the eastern United States show a contrasting trend of decreasing copper with a decreasing nickel-cobalt ratio (trend 2). Copper content in the trend 2 group is as much as one-half to one-third lower than it is in rocks of virtually identical major and stable trace-element composition. Geochemical features of trend 2 rocks are attributed to the strong partitioning of copper and nickel into an immiscible sulfide melt that separated from the magmas during ascent. Most tholeiitic basalts showing the largest copper depletion are in North and South Carolina. These contrasting trends of nickel-cobalt versus copper can be used to identify mafic rocks in which fractionation of nickel- and copper-bearing sulfide liquids took place and thus can be a guide in the exploration for magmatic nickel-copper deposits.

AERIAL PROFILING OF TERRAIN SYSTEM

- The U.S. Geological Survey has developed an airborne surveying system that is capable of surveying the terrain with very high accuracy from a low-flying aircraft using a laser profiler and inertial guidance technology. The Aerial Profiling of Terrain System (APT) consists of an inertial measuring unit, a laser

The Twin-Otter aircraft performing surveys over the Charles River west of Boston, Massachusetts, during applications testing of the Aerial Profiling of Terrain System.

profiler, a laser tracker, a computer, a video imaging system and supporting electronics, all mounted in a Twin-Otter aircraft. The inertial measuring unit provides an accurate reference frame to the local datum. The laser profiler measures the distance from the aircraft to the ground. Periodic positional updates are provided by the laser tracker, which measures range and angle from the inertial measuring unit to previously placed retroreflectors on the ground. The computer serves as a system controller, data collector, and processor, while continuously navigating the aircraft during data collection activities. The video system records the ground image below the aircraft. In addition to measuring accurate terrain profiles for flood-plain mapping, however, the unique capability of the system to provide rapidly survey data of centimeter accuracy with a minimal requirement for ground control offers numerous other possible uses, such as monitoring subsidence, testing of old maps for reliability, establishing control for new mapping, measuring volcanic swelling, and serving as an airborne gravity mapping instrument. The new system represents a revolutionary combination of advanced inertial guidance and laser technologies, by providing an airborne remote sensing platform that is unprecedented not only in precision but in mobility and speed of data acquisition as well. Operational testing of the system now is complete, and further efforts will focus on applications testing to demonstrate various uses in earth science data-collection activities.

SCREENING OF GEOHYDROLOGIC ENVIRONMENTS IN THE BASIN AND RANGE PROVINCE FOR HIGH-LEVEL RADIOACTIVE WASTE DISPOSAL

- Deeply buried repositories in specially constructed mines offer several properties suitable for disposal of high-level radioactive waste. Principal among these properties are adequate shielding, isolation from the environment, absorption and dispersion of heat generated by the radioactive waste, and protection from intrusion by man. The potential for migration of high-level radioactive wastes from the repository demands that attention be given not only to the selection of a suitable host material for the waste but also to the selection of the geohydrologic environment of the repository. The U.S. Geological Survey's program for identifying potential environments suitable for locating acceptable repositories in the Basin and Range province was an outgrowth of a plan developed jointly with the U.S. Department of Energy, which has the responsibility for selecting, building, and operating the repositories. Although this is a Geological Survey study, earth scientists from the particular States involved are participating actively.

OFFSHORE GEOLOGIC SURVEYS

- Seafloor sonar imaging of the Pacific conterminous Exclusive Economic Zone (EEZ) produced a spectacular mosaic revealing new underwater volcanos, faults, meandering river channels, and previously unknown aspects of spreading centers, deep sea fans, and major fracture zones. This activity, conducted in cooperation with the Institute of Oceanographic Sciences of England and using their Geologic Long Range Inclined Asdic (GLORIA) system, is the first such investigation to be completed under the U.S. Geological Survey's program that is being implemented in response to the President's proclamation of the EEZ. The results, to date, along the west coast have already had a profound effect on geologic theory regarding the evolution of the area, its energy- and mineral-resource potential, and potential geologic hazards.
- "Operation Deep Sweep" took the Research Vessel *Samuel P. Lee* from pole to pole across the Pacific

Research Vessel Samuel P. Lee *escaping from ice channel at McMurdo Sound, Antarctica. (Photograph by Steve Eittreim.)*

where new information was obtained on cobalt-rich seafloor encrustations and on the geologic setting and potential oil resources of the South Pacific islands. Additional information on the preliminary results of this cruise is found in the "Geologic Investigations" chapter.

GEOLOGIC HAZARDS STUDIES

- The northern Rocky Mountains were strongly shaken on October 28, 1983, by a magnitude 7.3 earthquake located near Borah Peak, Idaho—the largest magnitude event in the conterminous United States since 1959. The U.S. Geological Survey earthquake-investigation teams discovered that the earthquake was caused by movement on the Lost River fault. A fault rupture nearly 21 miles in length, with almost 9 feet of vertical offset, was discovered in the epicentral area. In 1975, the Geological Survey had identified the Lost River fault as potentially active; in 1982, Geological Survey scientists had calculated that the area including the Lost River fault could generate an earthquake of magnitude 7.
- A remarkable set of strong-ground motion recordings was obtained for the Morgan Hill, California, earthquake of April 24, 1984. The moderate-sized (magnitude 6.1) earthquake occurred on the Calaveras fault east of San Jose, within a dense network of U.S. Geological Survey earthquake-monitoring instruments that had been deployed earlier along the fault. The 1.3-gravity acceleration registered at a station near Morgan Hill was one of the largest horizontal accelerations ever recorded.
- Evidence of at least two, and possibly three, large prehistoric earthquakes has been discovered in the Charleston, South Carolina, area.

Buried liquefaction-related ground failures, apparently induced by earthquake shaking, have been found in sediments of late Quaternary age. The discoveries greatly lengthen the known seismic record of the Southeastern United States and indicate that the 1886 Charleston earthquake was not a unique event.

- nalyses of the association of precipitation and changing groundwater levels during episodes of damaging debris flow ("mudslide") activity in California in 1982 and in Utah in 1983 and 1984 confirm that debris-flow activity is triggered when intense rainfall or rapid snowmelt creates temporary near-surface water tables in soils and bedrock. Monitoring of rainfall and soil-moisture conditions may permit forecasts of increased landslide potential.

Landslide at Love Creek, near Ben Lomond, California, January 4, 1982.

SATELLITE IMAGE MAPPING

- The U.S. Geological Survey has long recognized the need for image maps as tools for resource analysis and as map supplements, as well as a means to provide coverage of unmapped areas. After Landsat 1 was launched in 1972, the Geological Survey began to produce multicolor maps from the multispectral scanner imagery, and earth scientists quickly recognized the global application of small-scale, image-base maps for compiling and analyzing land use, geologic, and hydrologic data over large regions. The Survey continued to develop optimum techniques for producing color-image maps at 1:250,000 scale from multispectral scanner imagery. Imagery from the higher resolution Landsat 4 Thematic Mapper recently has made possible the production of color-image maps at 1:100,000 scale. Advances in image-mapping science at the Geological Survey include the development of innovative techniques for geodetic control extension, computer processing for enhancement of digital image data, photographic and digital mosaicking, and calibrated lithographic printing. Current research includes (1) refining computer technqiues for digital mosaicking of Landsat image data over areas as large as 6° in latitude and longitude and extracting individual quadrangles for more efficient image-map production, (2) developing methods for preparing map separates directly from computer tapes, (3) improving digital techniques for geometric correction and image enhancement, and (4)

Reduced version of the image from Landsat 4 Thematic Mapper data used to prepare the Washington, D.C., and Vicinity image map at 1:100,000 scale. It is printed here at approximately 1:550,000 scale.

combining Landsat data with other digital data sets, such as elevation data, for analysis in automated geographic information systems.

HIGH PLAINS REGIONAL AQUIFER SYSTEM ANALYSIS PROJECT

- The High Plains, a 174,000-square-mile area of flat to gently rolling terrain east of the Rocky Mountains, is underlain by unconsolidated alluvial deposits that form a water-table aquifer capable of sustaining well yields of 100 to more than 1,000 gallons per minute. Irrigation from this aquifer has made the High Plains one of the Nation's leading agricultural areas. In 1978, as part of the Regional Aquifer System Analysis (RASA) Program, the U.S. Geological Survey began a study of the High Plains aquifer to understand the flow system and to evaluate the effects of the irrigation development on a regional scale. This study indicated that data on pumpage for irrigation and recharge to the aquifer from irrigation return flow are essential to evaluate water-level declines due to irrigation development; these data, however, were not readily available. To develop a method of estimating these data with an acceptable confidence level, a follow-up project to the RASA Program, Phase II, was started in 1983, and two areas, one in the southern High Plains of Texas and the other in the northern High Plains of Nebraska, are being studied currently.

ENERGY GEOLOGIC STUDIES

- During fiscal year 1984, several geological and hydrological studies at Newberry Volcano, Oregon, were completed under the Geothermal Research Program. Results of these studies provided (1) evidence from hydrothermal alteration analyses that a hot, young hydrothermal system still is evolving beneath the volcano, (2) a conceptual model of the shallow hydrothermal system that estimates fluid recharge to the system, and (3) a related numerical model of conductive heat flow that refines estimates of the age and size of a shallow magma chamber which would be the heat source for the hydrothermal system. These studies followed test drilling by the U.S. Geological Survey at Newberry Volcano in 1981 that demonstrated that high-temperature geothermal fluids exist in permeable rocks beneath a cool zone of hydrologic masking. The investigations at Newberry have substantiated the concept that the potential for exploitable geothermal energy in the Cascade Range of the Pacific Northwest is high and have provided incentives for additional industry exploration in the region.
- Assessment of the undiscovered oil and gas resources of the United States and worldwide continued in fiscal year 1984. A major focus has been on the pattern of worldwide hydrocarbon exploration drilling, and methods of predicting oil and gas reserves from past production records are being developed. Results of this research indicate that areas for new exploration still are expanding at the relatively rapid rate of 50,000 square miles per year (now covering 1.5 million square miles outside North America and Communist countries), but a large fraction of new additions to reserves may be generated from already discovered fields. Another topic being studied is the pattern of oil and gas field size distributions in mature basins. The results of this study will allow future regional resource estimation methods to be expanded to include predictions of field size distributions as well as aggregate amounts of petroleum.
- Two maps showing the location and names of basins and the total thickness of sedimentary rocks in the conterminous United States and two maps showing the location of wells drilled for oil and gas deeper than 15,000 and 20,000 feet, respectively, in the onshore and offshore conterminous United States were released January 1984. These maps are now being refined and,

when formally published, will be the first components of an *Atlas of Oil and Gas Data.*

DIGITAL SYSTEMS

- Digital systems used by the U.S. Geological Survey to collect, process, edit, and display digital cartographic data are in a state of rapidly changing technology. During the 1970's, such systems were simply tools to digitize manually features from maps and aerial photographs and to store the data onto magnetic tapes. Currently, systems are available which not only collect data but have the interactive capability to display and edit the data, greatly improving the accuracy and economy of producing digital data with a high level of data integrity and completeness. One type of digital system is used to scan maps automatically and uniformly, to digitize features of a particular overlay or of a certain color, and to store the data in a televisionlike format. An associated computer and an edit station then are used to correct errors, to label features, and to reformat the data. Another type of digital system is used to trace lines and to digitize their coordinates directly, with feature labels or attributes being added concurrently. The digitizing may be accomplished manually and then viewed and edited interactively, or it may be accomplished automatically by a line-following sensor with some interactive assistance. Edit systems now have color capability to aid in complex interpretation and computers large enough for extensive processing and analysis. As digital systems continue to evolve, the economic acquisition of digital data, the plotting of cartographic products, and the application of data in geographic information systems for resource analysis will increase dramatically. These evolving capabilities will revolutionize map production and geographically based resource analyses.

MOVEMENT AND FATE OF CONTAMINANTS FROM TREATED SEWAGE INFILTRATED TO GROUND WATER, CAPE COD, MASSACHUSETTS

- Since 1936, secondarily treated domestic sewage has been discharged to the ground on surface sand beds at a sewage-treatment plant at Otis Air Force Base, Massachusetts. Infiltration of the sewage through sand beds to an underlying sand and gravel aquifer and the subsequent movement of the sewage-contaminated ground water in a southerly direction have caused a plume of contamination to form that is 3,000 feet wide, 75 feet thick, and more than 11,000 feet long. Most contaminants move readily through the sand and gravel that make up the aquifer on Cape Cod, and little discernible attenuation by sorption of solutes on the aquifer material is evident. Transverse and longitudinal spreading of the plume is significant, but little vertical mixing occurs. After 10,000 feet of movement, the plume is only about 75 feet thick, with a core zone 20 to 30 feet thick where the contaminants remain at concentrations more than one-fourth of what they are in the treated sewage.

LAND-RESOURCE INVESTIGATIONS

- An extensive subduction melange complex, the Macon melange, which underlies at least 5,000 square miles in Georgia, has been recognized through detailed geologic mapping conducted under the Geologic Framework Program in the Georgia Piedmont. A melange is a deformed mixture of rocks made up of slabs and blocks, some of them miles in length, that have been mixed together by movements between the continent-sized plates that form the Earth's crust. The Macon melange may be comparable in size to the Franciscan melange complex in California, which is one of the best known in North America. Evidence from structures preserved in the rocks indicates that this mixture of diverse rock materials formed above an "African" subduction zone at which the crustal plate that formed the floor of the ocean at that time was pushed beneath the African continent, and sediments resting on the plate were scraped off and piled up on or near Africa. This event occurred when Africa, North America, and South America were joined together as a single continent about 225 million years ago. Geologic mapping and chronological studies conducted under the Geologic Framework Program continue to increase our knowledge of past and present interaction between the huge plates that make up the Earth's crust. These studies have extensive practical applications for industry and government in such diverse fields as mineral and energy exploration and geologic hazard studies.

- Continued detailed geologic mapping in California is redefining the origin of the San Andreas and other faults and the amount and rate of displacement on them. This mapping bears heavily on regional multidisciplinary syntheses which are documenting the accretion of exotic terranes (microcontinents that did not originate in North America) from around the Pacific onto the western margin of North America. Mapping older rocks in areas adjacent to the San Andreas fault system has increased our understanding of its evolution. Geologists doing the geologic mapping have reconstructed the distribution pattern of these older rocks before to their offset by the San Andreas and related faults that transect the mountain ranges of southern California.
- An early 20th century uplift of a major part of southern California closely matches a mid-20th century uplift in areal extent and magnitude, as well as in its history of episodic growth and partial collapse. The detection of this earlier uplift, together with the previous recognition of its modern analogue in southern California, demonstrates that a very large part of southern California, including the major mountain ranges bounding the north side of Los Angeles, has sustained cyclic deformation over a period of about 50 years. This finding is critical to an assessment of the tectonic evolution of the boundary between the actively moving North American and Pacific crustal plates and will be an important consideration for any tectonic model used for earthquake prediction in this heavily populated and economically vital region.
- Exciting new analytical techniques are being employed which now make it possible to determine the ages of rocks and sediments that previously could not be dated. An example is the laser argon-40–argon-39 method, by which ages of single grains of mica can be measured without having to go through the time-consuming and expensive process of separating the mineral from the rock. This dating process aids greatly in understanding the chronology of mineralized zones where micas are present in such small quantities or are so small that they cannot be separated for conventional dating.

LASER OPTICAL DISK STORAGE

- Research and development are underway to implement laser optical disk storage technology for the storage, retrieval, and maintenance of the rapidly expanding National Digital Cartographic Data Base. Optical disk technology involves the use of laser beams to read and record digital information onto and from the surface of a rotating reflective disk. The optical disk unit records information on the reflective surface by burning microscopic patterns of digitally encoded pits with a high-powered laser. The unit reads the information from the disk with a second laser which illuminates the burned areas, reflects the encoded pattern to a photoelectric sensor, and converts the resulting electrical impulses to digital signals for data processing. This promising technology offers significant advantages over conventional storage and retrieval devices. For instance, magnetic tapes and disks normally degrade after 2 or 3 years, while optical disks are expected to last at least 10 years. Optical technology also offers far higher data storage capability. A single disk can store up to 4 × 109 characters of data—an amount equivalent to 40 magnetic tapes. When the new software is developed, the use of optical disks will reduce significantly the costs of the National Digital Cartographic Data Base and other archival storage. Current research and development efforts are moving toward improving data structures, data access methods, and data processing procedures to efficiently use the technology.

DISINTEGRATION OF THE LOWER REACH OF COLUMBIA GLACIER, ALASKA, NOW UNDER WAY

- During the time in the mid 1970's when the Trans-Alaska Pipeline terminal was being built, ice in the shipping lanes of Valdez Arm was encountered rarely and was not considered to be a problem. Now, however, icebergs are seen frequently in Valdez Arm, and, occasionally, tankships have to be diverted or delayed because of ice. Icebergs in Valdez Arm are increasing because the Columbia Glacier is beginning to disintegrate rapidly, resulting in a large increase in the breaking off (calving) of icebergs. This rapid disintegration was predicted by U.S. Geological Survey glaciologists

U.S. Geological Survey scientist with ablatograph that will record ice melt on Columbia Glacier, (Photograph by Mark E. Meier, U.S. Geological Survey.)

in 1980. Never before have scientists been able to observe the beginning of glacier instability and drastic retreat, and careful observations of this glacier are adding much valuable new information, some of which is surprising and unanticipated.

MAPPING OF IRRIGATED CROPLAND WITH LANDSAT DIGITAL DATA

- Research in the use of multispectral Landsat digital data has proved that this type of data can be used to estimate indirectly water withdrawal from irrigated cropland acreage. The High Plains aquifer, covering parts of eight Midwestern States, supplies water for one-quarter of the Nation's irrigated agriculture, and the aquifer is being depleted rapidly with little natural recharge. A computerized hydrologic model is being developed by staff members of the U.S. Geological Survey's High Plains Regional Aquifer Systems Analysis Project to assist in evaluating effects of future ground-water pumpage. The key evaluation factor is current water pumpage, which is estimated from measuring the amount of land that is irrigated and knowing how much water is used to irrigate an average acre. Multispectral Landsat digital data were used to map rapidly the irrigated cropland over the aquifer. The data were computer processed to establish spectral classes, and, through a clustering process, each Landsat scene was classified to identify accurately irrigated cropland. In some areas, the variation in crops required scenes spanning several seasons. The final area measurements were combined with estimated pumpage rates to successfully provide input to the hydrologic model. This method provided classification of the cropland rapidly and accurately.

PLANETARY GEOLOGY

- The first in a series of three 1:15,000,000-scale geologic maps of Mars made from Viking Orbiter spacecraft images has been completed for the National Aeronautics and Space Administration. The series will supersede the Geologic Map of Mars (1:25,000,000 scale) completed in 1978 from Mariner 9 spacecraft pictures. The new map of the Western Equatorial Region shows 60 individual rock-stratigraphic units and includes descriptions of major tectonic, volcanic, and fluvial (river development) episodes interpreted from the spacecraft image data. The expanding Martian data base includes a new series of photomosaics and a new planetwide topographic data control net.
- Evidence of prehistoric, large-scale climate change was observed from space shuttle orbit. Ground investigation of buried ancient stream channels in the eastern Sahara dicovered by U.S. Geological Survey and other scientists resulted from analysis of images made by the Imaging Radar System in an early 1982 shuttle flight. The field observations, in addition, are providing important new data to evaluate subsurface radar responses for water and mineral resource potential, and for defining habitation patterns and migration paths of early stone age man about 200,000 years ago.

Missions, Organization, and Budget

MISSIONS

The U.S. Geological Survey was established by an Act of Congress on March 3, 1879, to answer the need for a permanent agency at the Federal level to conduct, on a continuing, systematic, and scientific basis, investigations of the "geological structure, mineral resources, and products of the national domain." Although a number of laws and executive orders have expanded and modified the scope of the Survey's responsibilities over its 104-year history, the Survey has remained principally a scientific and technical investigation agency as contrasted with a developmental or regulatory one. Today, the Survey is mandated to assess onshore and offshore energy and mineral resources; to provide information for society to mitigate the impact of floods, earthquakes, landslides, volcanoes, and droughts; to monitor the Nation's ground- and surface-water supplies; to study the impact of man on the Nation's water resources; and to provide mapped information on the Nation's landscape and land use. The Survey is the principal source of scientific and technical expertise in the earth sciences within the Department of the Interior and the Federal Government. This *Yearbook* provides highlights of the wide range of earth science research and services in the fields of geology, hydrology, and cartography.

ORGANIZATION

The U.S. Geological Survey is headquartered in Reston, Virginia. Its activities are administered through the major program divisions of National Mapping, Geologic, and Water Resources. These program operations are supported by the Administrative and the Information Systems Divisions. The Survey conducts its functions through an extensive field organization of offices located throughout the 50 States and Puerto Rico. At the national level, the functions of the Survey are coordinated through assistant directors for administration, program analysis, research, information systems, intergovernmental affairs, and engineering geology.

BUDGET

In fiscal year 1984, the U.S. Geological Survey had obligational authority for $579.9 million, of which $367.1 million came from direct appropriations, $30.3 million came from transfers of the unobligated balance ($24.0 million) from the National Petroleum Reserve in Alaska account as required in the appropriation language and from the Office of Water Policy for the Water Resources Research Institutes ($6.35 million), $8.5 million came from estimated receipts from map sales, and $174.0 million came from reimbursements. The Survey also received funds for reimbursable work performed under agreements with other Federal agencies, State and local governments, international organizations, and foreign governments. The Survey performs services under these agreements when earth science expertise is required by other agencies and their needs complement Survey program objectives. Work done for State, county, and municipal agencies is almost always done on a cost-sharing basis.

Most of the appropriations and reimbursements received by the Survey in fiscal year 1984 are distributed through

Percentage allocation of funds, by Division budget activities that roughly correspond to its mapping, geologic, hydrologic, and administrative areas of responsibility.

U.S. Geological Survey budget authority for fiscal year 1984, by appropriation
(Dollars in thousands)

Activity/Subactivity/ Program Element	Fiscal year 1984[1] enacted
Surveys, Investigations, and Research:	
National Mapping, Geography, and Surveys	**90,985**
Primary Quadrangle Mapping	**32,999**
Primary Quadrangle Mapping	29,145
Modernization of Mapping Technology	3,854
Map Revision and Orthophotoquads	**12,497**
Revision	8,207
Orthoquads	4,290
Digital Mapping	**8,103**
Small, Intermediate, and Special Mapping	**13,699**
Intermediate-Scale Mapping	5,477
Small-Scale and Other Special Mapping	2,106
Federal Mineral Land Information	1,000
Land Use and Land Cover Mapping	3,425
Airborne Profiling of Terrain System	1,691
Earth Resources Observation Systems	**9,667**
Cartographic and Geographic Information	**4,020**
Receipts for Printing and Distribution	**8,500**
Side-Looking Airborne Radar	**1,500**
Geologic and Mineral Resource Surveys and Mapping	**164,354**
Geologic Hazards Surveys	**52,495**
Earthquake Hazards Reduction	35,568
Volcano Hazards	11,651
Ground Failure and Construction Hazards	2,076
Reactor Hazards Research	3,200
Land Resource Surveys	**17,419**
Geologic Framework	14,233
Geomagnetism	2,174
Climate Change	1,012
Mineral Resource Surveys	**45,355**
Alaska Mineral Surveys	9,435
Conterminous U.S. Mineral Surveys	5,776
Wilderness Mineral Surveys	8,399
Strategic and Critical Minerals	9,310
Development of Assessment Techniques	12,435
Energy Geologic Surveys	**30,389**
Coal Investigations	11,283
Onshore Oil and Gas Investigations	6,619
Oil Shale Investigations	547
Geothermal Investigations	7,284
Uranium–Thorium Investigations	4,155
World Energy Resource Assessment	501
Offshore Geologic Surveys	**18,696**
Offshore Geologic Framework	18,696
Water Resources Investigations	**129,441**
National Water Data System—Federal Program	**61,063**
Data Collection and Analysis	16,443
National Water Data Exchange	1,288
Regional Aquifer Systems Analyses	15,197
Coordination of Water Data Activities	932
Core Program Hydrologic Research	7,271
Improved Instrumentation	1,955
Water Resources Assessment	1,346
Supporting Services	3,344
Toxic Wastes—Ground Contamination	8,586
Acid Rain	3,050
Environmental Affairs	748
Water Resources Scientific Information Center	903
Federal–State Cooperative Program	**50,001**
Data Collection and Analysis, Areal Appraisals, and Special Studies	42,800
Water Use (Cooperative)	3,886
Coal Hydrology (Cooperative)	3,315
Water Resources Research Institute	**6,353**
Energy Hydrology	**12,024**
Coal Hydrology	4,443
Nuclear Energy Hydrology	7,274
Oil Shale Hydrology	307
General Administration	**15,642**
Executive Direction	4,970
Administrative Operations	8,633
Reimbursements to the Department of Labor	2,039
Facilities	**10,463**
National Center—Standard Level User's Charge	8,762
National Center—Facilities Management	1,701
TOTAL, Surveys, Investigations, and Research	**410,885**
Barrow Area Gas Operation	**13,000**
TOTAL, U.S. Geological Survey	**423,885**

[1] Funding shown represents appropriated dollars and does not include reimbursable funding from Federal, State, and other non-Federal sources.

PERSONNEL

At the end of fiscal year 1984, the U.S. Geological Survey had 7,911 permanent full-time employees on board. The Survey's diversified earth science research programs and services are reflected in its workforce which is composed of personnel in over 170 disciplines, with more than 50 percent possessing a Bachelor's or higher level degree. More than one-half of the Survey's staff are professional scientists, and approximately one-fourth are technical specialists. Hydrologists, geologists, and cartographers predominate among the professional group which includes members of more than 30 other disciplines, such as geophysicists, chemists, and engineers.

The permanent employees are supported by other than full-time permanent employees which include many students and faculty members from colleges and universities as well as part-time personnel. The Survey has profited greatly from its relations with the academic community. The expertise of many eminent specialists has become available to the Survey in this manner and has provided great flexibility in solving problems and meeting surges in workload, especially during the field season. Those associations also have been an invaluable channel for recruiting young professionals of demonstrated ability for permanent full-time positions upon the completion of their studies.

AWARDS AND HONORS

Each year, employees of the U.S. Geological Survey receive awards that range from modest monetary awards to recognition of their achievements by large professional societies. The large number of these awards attests to the quality of the individuals who are the U.S. Geological Survey. This year, the Survey wishes to acknowledge those individuals who either received high honors from or were elected to high office in professional societies.

Honors

Paul B. Barton, Geologist, was the recipient of the Roebling Medal of the Mineralogical Society of America for his pioneering work in ore petrology.

Thomas J. Buchanan, Associate Chief Hydrologist for Operations, was named Engineer of the Year for the U.S. Geological Survey, Department of the Interior, by the National Society of Professional Engineers.

Steven M. Colman, Geologist, received the Kirk Bryan Award of the Geological Society of America for his highly significant research on chemical weathering of volcanic rocks.

Frederick J. Doyle, Research Cartographer, was awarded the Brock Gold Medal for outstanding contributions to the evolution of photogrammetry by the International Society for Photogrammetry and Remote Sensing.

Edwin B. Eckel, Geologist, received the Geological Society of America Engineering Geology Division's Distinguished Practice Award.

David L. Jones, Geologist, was appointed a Distinguished Lecturer by the American Association of Petroleum Geologists.

Mary C. Rabbitt, Geophysicist, was honored by the Geological Society of America with its History of Geology Award for her authorship of the first two volumes of the history of the U.S. Geological Survey.

Eugene M. Shoemaker, Geologist, was awarded the Barringer Medal of the Meteoritical Society, in recognition for his pioneering research in the physics of impact cratering phenomena and the role of impacts in the history of the planets; he also received the Kuiper Prize of the American Astronomical Society for his fundamental contribution to planetary science.

Laurence A. Soderblom, Geologist, was the recipient of the Public Service Award, National Aeronautics and Space Administration, for meritorious personal contributions to their space science programs.

Charles V. Theis, Hydrologist, received the Horton Medal of the American Geophysical Union for his outstanding contributions to groundwater hydrology.

Edwin P. Weeks, Hydrologist, received the O. E. Meinzer Award of the Geological Society of America for his paper entitled *Field Determinations of Vertical Permeability* to Air in the Unsaturated Zone, published as U.S. Geological Survey Professional Paper 1051.

Donald E. White, Geologist, was awarded the Penrose Medal of the Geological Society of America in recognition of his outstanding research on hydrothermal systems.

Presidents and Chairmanships of Professional Societies

Service in professional societies is one of the important professional contributions a scientist can make. Societies play a fundamental role in distributing new knowledge, as well as providing a forum in which new ideas are tested. The active participation of Survey scientists in professional societies attests to the scientific vitality of the Bureau. The Bureau is particularly proud of those individuals who have been elected to society presidencies, or chairmanships of major sections of societies, by their professional peers.

G. Brent Dalrymple	Volcanology, Geochemistry, and Petrology Section, American Geophysical Union
Joel L. Morrison	International Cartographic Association
R. Anthony Novotny, Jr.	American Cartographic Association
David A. Rickert	American Water Resources Association
Laurence A. Soderblom	Planetology Section, American Geophysical Union

National Mapping Program

MISSION

The National Mapping Division conducts the National Mapping Program, which provides graphic and digital cartographic and geographic products and information for the United States, Territories, and U.S. possessions. The products include several series of topographic maps, photoimage maps, land use and land cover maps and associated data, geographic names information, geodetic control data, and remotely sensed data.

The products are generated by four regional mapping centers and the Earth Resources Observation Systems Data Center. The Division's Printing and Distribution Center prints, stores, and distributes all Geological Survey maps and texts. The Division also operates Public Inquiries Offices and National Cartographic Information Centers which, along with the Earth Resources Observation Systems Data Center, provide information about and fill orders for cartographic, geographic, earth science, and remotely sensed data.

MAJOR PROGRAMS AND ACTIVITIES

In support of the National Mapping Program, the Division concentrates its efforts on the following major activities:

- Primary quadrangle mapping and revision, including the production and revision of 7.5-minute 1:24,000- and, in selected areas, 1:25,000-scale topographic maps in the conterminous United States and Hawaii and the 15-minute 1:63,360-scale topographic maps in Alaska. During fiscal year 1984, about 1,300 revised and 1,600 new primary quadrangle maps were published, mostly in the 7.5-minute series. Published topographic maps

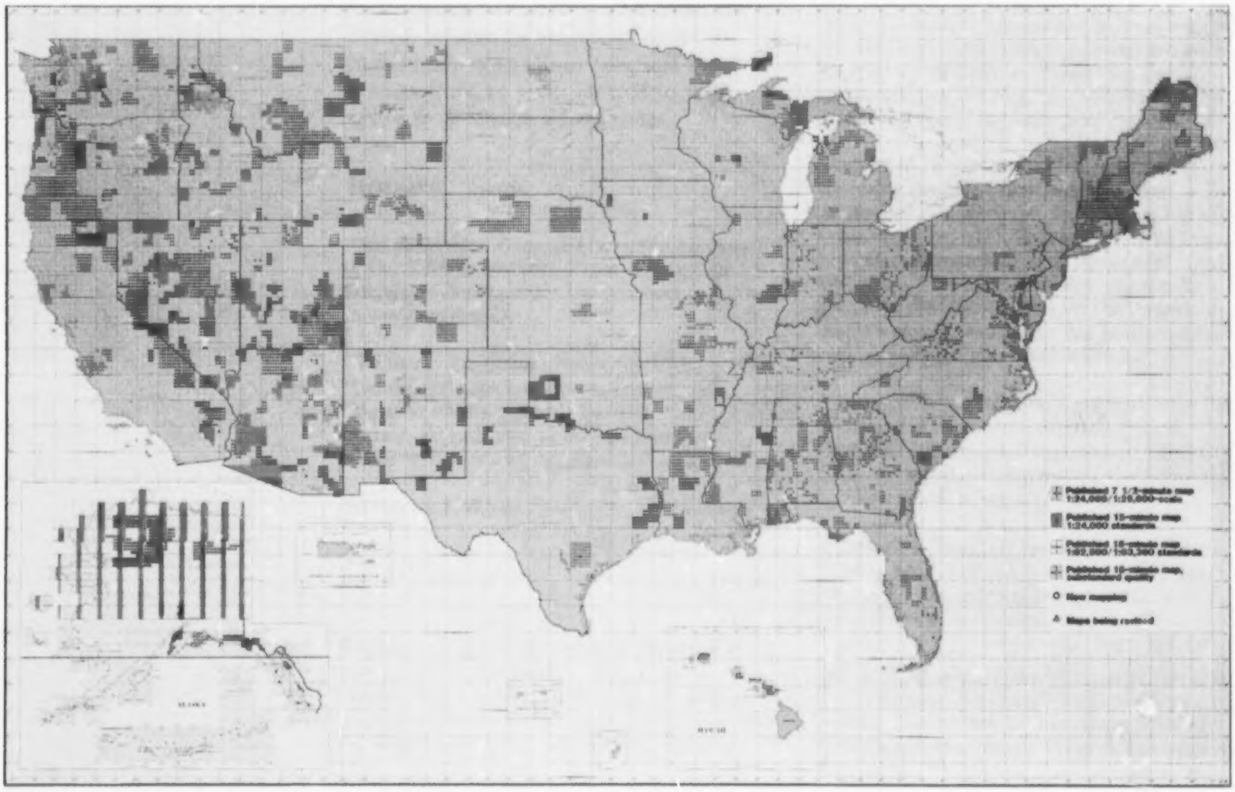
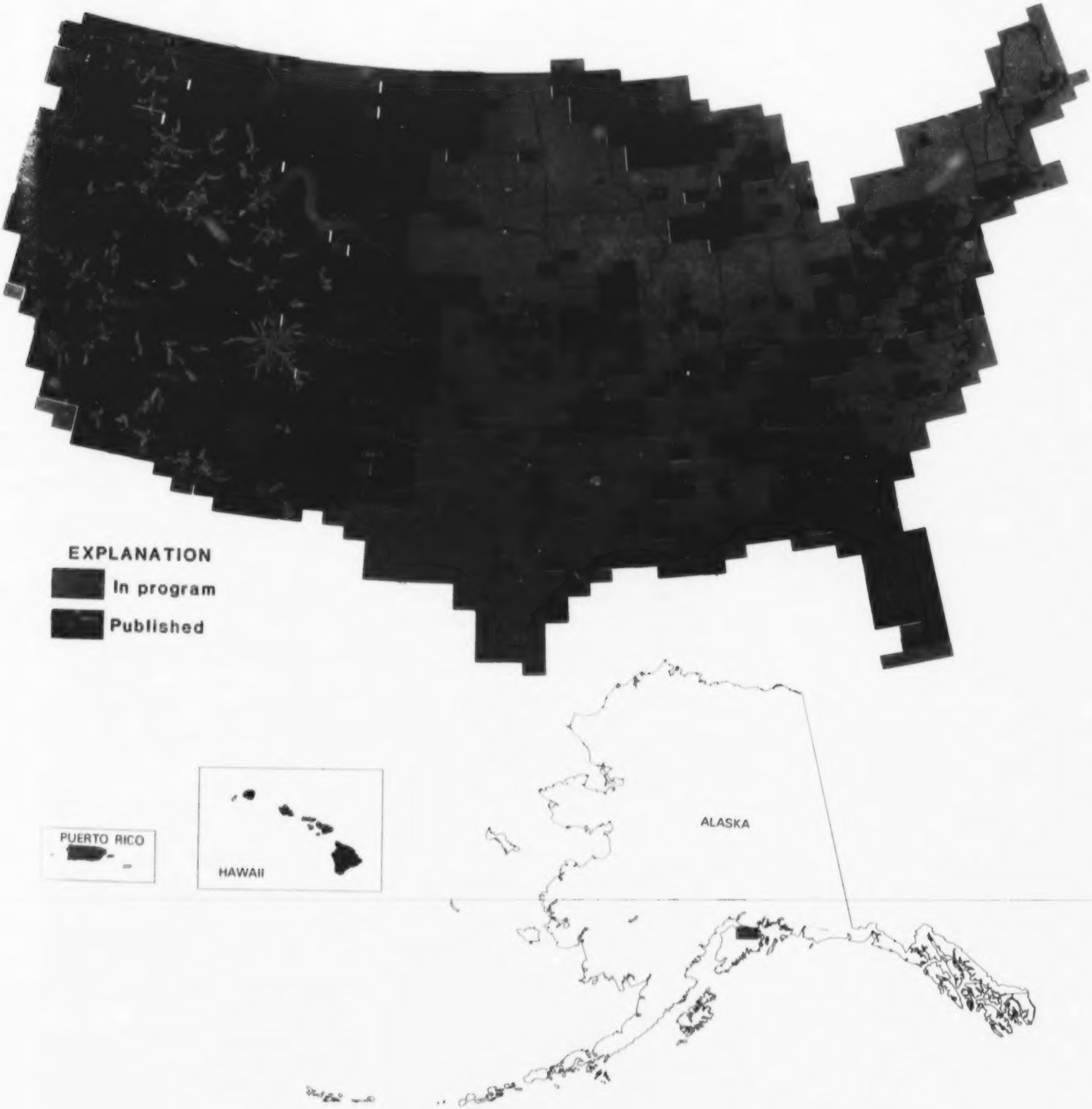

Published 7 1/2-minute map 1:24,000/1:25,000-scale
Published 15-minute map 1:24,000 standards
Published 15-minute map 1:62,500/1:63,360 standards
Published 15-minute map, substandard quality
New mapping
Maps being revised

Figure 1. *Status of primary quadrangle mapping and revision program. [Reduced version of 1984 status map. Full-size map available from Public Inquiries Offices.]*

are available for about 85 percent of Alaska and for 84 percent of the other 49-State area (fig. 1). Sixteen States have complete 7.5-minute series map coverage.

- Small-scale and special mapping, including the preparation of maps and map products from the intermediate-scale (1:50,000 and 1:100,000) series to the small-scale (1:250,000) series and other smaller scale U.S. base maps. Complete topographic coverage of the United States is available at the scale of 1:250,000. More than 75 percent of the conterminous United States is mapped in one or more of the intermediate-scale series (fig. 2), which include 1:50,000-scale topographic quadrangle maps, 1:50,000- or 1:100,000-scale

Figure 2. *Status of intermediate-scale mapping program.*



topographic or planimetric county maps, and 1:100,000-scale topographic or planimetric quadrangle maps. More than 150 topographic-bathymetric maps have been published for coastal area planning. Land use and land cover maps are complete for 2.5 million square miles and are available in the 1:250,000-scale or, in selected areas, in the 1:100,000-scale quadrangle format.

- Digital cartography, including the production of base categories of cartographic data at standard scales, accuracies, and formats suitable for computer-based analysis. The Geological Survey chairs a Department of the Interior committee to coordinate digital cartography activities within the Department. Additionally, the Office of Management and Budget issued a memorandum to foster better coordination of digital cartography activities in all Federal agencies. The Geological Survey has been delegated the lead role in this activity and chairs the Federal Interagency Coordinating Committee on Digital Cartography.

- Information and data services, including the acquisition and dissemination of information about U.S. maps, charts, aerial and space photographs and images, geodetic control, cartographic and geographic digital data, and other related information; distribution of earth science information to the public; and sale of maps and map-related products directly and through over 3,300 commercial dealers.

- Advanced development and engineering to improve the quality of standard products; to provide new products, such as digital cartographic data, that make maps and map-related information more useful to users; to reduce costs and to increase productivity of mapping activities; to acquire innovative and more useful equipment; and to design and develop techniques and systems to advance the mapping of high-priority areas of the country.

- Cartographic and geographic research with particular emphasis on spatial data techniques for studies using modern geographic analysis with new and improved cartographic concepts and techniques.

- International activities, including the coordination of the Division's participation in international cartographic, geographic, surveying, remote sensing, and other map-related activities.

BUDGET AND PERSONNEL

For fiscal year 1984, National Mapping Division funding totaled about $110 million. Funding sources included direct congressional appropriations, funds transferred from other Federal agencies, joint funding agreements through the Federal-State Cooperative Program, funds transferred from local agencies, and funds received from the sale of published maps.

The permanent full-time personnel strength of the Division at the end of fiscal year 1984 was 1,904, representing a work force skilled in cartography, geography, computer science, engineering, physical science, photographic and remote sensing technology, and information sciences.

HIGHLIGHTS

In the following sections, highlights from some of the major activities are described.

Provisional Maps

In 1982, the Geological Survey initiated a series of provisional edition topographic maps to expedite completion of the 8,500 7.5-minute quadrangle areas not covered by 1:24,000-scale mapping. Under this accelerated mapping program, almost all of the unmapped areas are targeted for provisional mapping, which will allow completion of 7.5-minute map coverage of the conterminous United States in fiscal year 1989. Provisional maps of unmapped 15-minute quadrangle areas in Alaska also will be produced allowing 1:63,360-scale map coverage of Alaska to be completed concurrently with the 1:24,000-scale coverage of the conterminous United States.

Provisional maps are prepared to the same map accuracy standards and contain essentially the same level of content as standard topographic maps but reflect a provisional rather than a finished map appearance. They are printed in four or five colors and are made available through standard distribution procedures. The maps can be produced manually or with automated techniques. The first maps in the provisional series were produced manually using standard compilation techniques, with some linework and lettering done by hand.

Computer technology is the basis for the automated processing of provisional maps. Maps are produced in the following stages: (1) *information collection*: aerial photographs are used in plotting equipment to record information from the photographs on computer tapes, (2) *information editing*: appropriate map symbols are applied to represent properly the features on the map, and errors and deficiencies are corrected, and (3) *cartographic plotting*: newly developed computer programs produce and position certain descriptive lettering, contour labels, and control elevations on the maps. These automated processes further shorten the map production cycle for provisional maps and place the product in the hands of the user at an earlier date.

After completion of the provisional mapping program, the provisional maps will be republished as standard editions in conjunction with the revision of these maps.

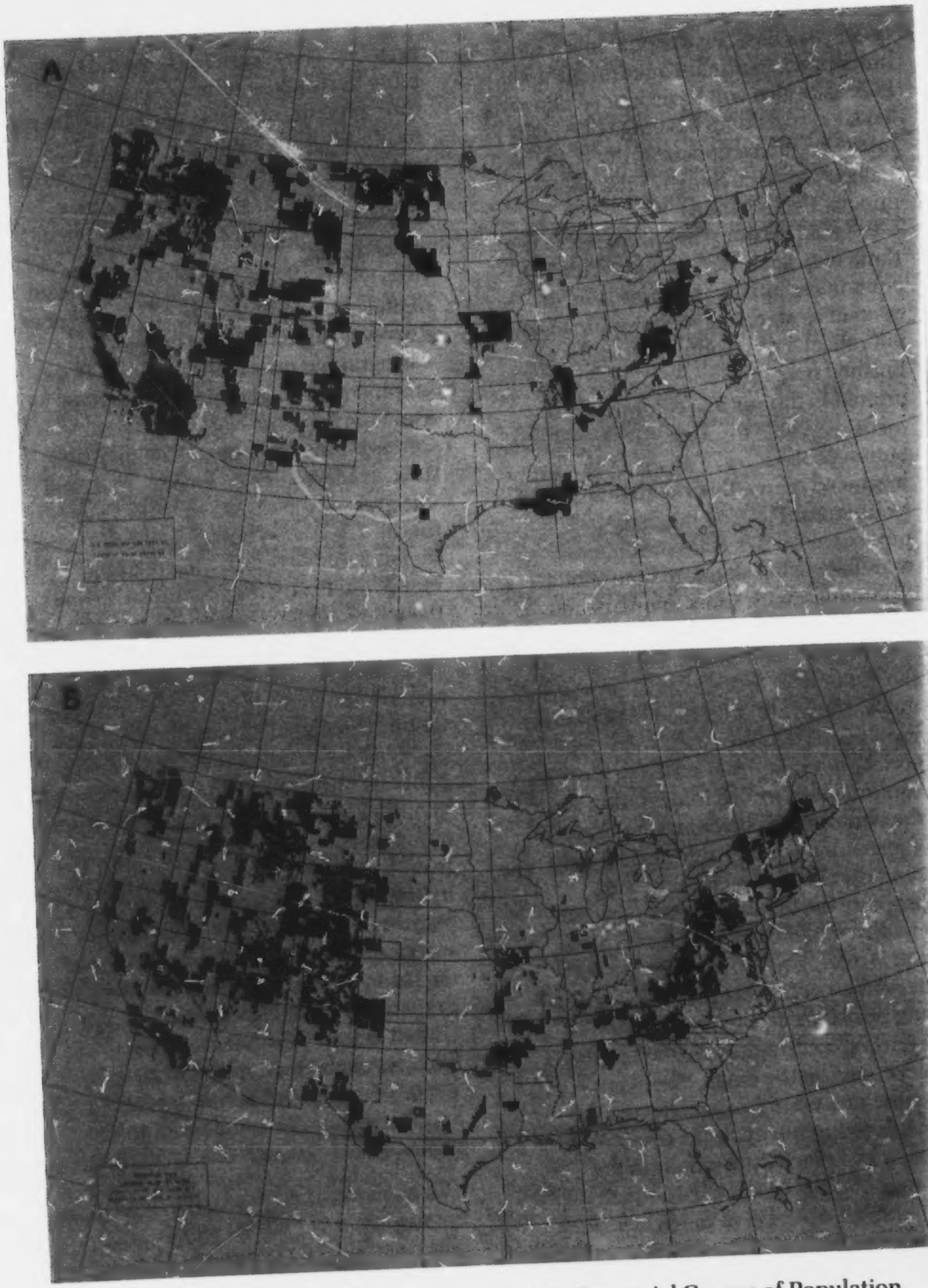
Digital Cartography

Map data in digital form are being applied to an increasing number of complex problems. Applications are not limited to the earth sciences but address many diverse and complex problems. An important factor in the growth of digital cartographic data applications is the development of geographic information systems. These systems have the capability to compare rapidly and sort through large amounts of digital data on multiple topics about the land and its resources. Maps depicting the results of the analysis can be prepared quickly and more accurately using automated procedures.

To meet the demand for standardized digital cartographic data, the Geological Survey is digitizing base categories of cartographic information from its topographic maps and making these data available from the National Digital Cartographic Data Base. The digitized data, available in two forms, are digital line graphs and digital elevation models (fig. 3). The digital line graphs are digital data files consisting of planimetric (line map) information. Currently, the following four categories of digital line graphs are being collected from 1:24,000-scale maps: the public land net, boundaries, hydrography, and transportation. The digital elevation models are digitized elevations shown at 30-meter intervals horizontally throughout a quadrangle. Hydrography and transportation features also are being digitized from 1:100,000-scale maps. Boundary, hydrography, and transportation features from the 1:2,000,000-scale sectional maps of the *National Atlas of the United States of America* are available in digital form for the entire United States. The data base also includes elevation data from the 1:250,000-scale map series, land use and land cover data, and geographic names data.

In a related area of activity, the coordination of Federal digital cartographic data programs, the Geological Survey expanded its coordination activities within the Department of the Interior by chairing the Interior Digital Cartography Coordination Committee. Also, the Geological Survey was delegated the lead role in implementing the Office of Management and Budget objective of fostering better coordination of all Federal digital cartography programs. In that role, the Geological Survey chairs the Federal Interagency Coordinating Committee on Digital Cartography. The Geological Survey continues to identify and respond to

Figure 3. *Digital cartographic mapping. A, Status of digital line graph production. B, Status of digital elevation model production.*



Federal digital cartographic data requirements, to provide a mechanism for the development of data standards, to serve as a forum for exchange of information on digital technology and methods, and to facilitate private sector use of the data.

Through this expanded Federal coordination activity, significant new requirements for digital cartographic data have been identified. The most pressing of these requirements is the development of a 1:100,000-scale digital cartographic data base to support the 1990 Decennial Census of Population. Accordingly, a major project is underway by the Geological Survey in cooperation with the Bureau of the Census to digitize transportation and hydrography data by mid-fiscal year 1987 for the 1,807 1:100,000-scale quadrangles covering the conterminous United States.

Image Mapping

The Geological Survey recognizes a national need for image products as valuable mapping tools, map supplements, and as alternatives to standard maps. As a result, it responds to these needs through the image mapping program.

Image mapping in the form of orthophotoquads provides relatively low-cost products that can be prepared in about one-third of the time required for line maps. For areas of the conterminous United States unmapped at the 1:24,000 scale, black-and-white orthophotoquads serve as interim maps until new 7.5-minute topographic maps become available. For areas with 7.5-minute map coverage, orthophotoquads serve as map supplements. Orthophotoquads have been prepared for about 57 percent of the conterminous United States. During fiscal year 1984, the Geological Survey prepared about 1,900 orthophotoquads.

In Alaska, 15-minute orthophotoquads are being prepared at the 1:63,360 scale in cooperation with the Bureau of Land Management and the State of Alaska. In fiscal year 1984, 140 quadrangles were produced. Coverage of most portions of the State is anticipated over the next decade.

Responding to requirements of the U.S. Customs Service and the International Boundary and Water Commission, the Geological Survey is preparing maps of the international boundary between the United States and Mexico. Currently, 48 of the projected 201 photoimage maps in simulated natural color at 1:25,000 scale have been published.

The Geological Survey has been experimenting with Landsat imagery to assess its utility in the production of image maps which can be used in a variety of earth science applications. Landsat image mapping products which have been completed are the experimental Las Vegas Landsat 3 multispectral scanner 1:250,000-scale image map (as shown on the *Yearbook* cover), the Dyersburg, Tennessee-Missouri-Kentucky-Arkansas 1:100,000-scale image map, and the Washington, D.C., and Vicinity Landsat 4 Thematic Mapper 1:100,000-scale image map. The National Mapping Division will prepare about 25 Landsat image products annually in fiscal years 1985 and 1986 to meet emerging requirements.

On July 2, 1984, the Great Salt Lake, Utah, crested at a peak elevation of 4209.25 feet above mean sea level, the highest lake elevation since July 1, 1878. This recent high lake level was recorded successfully on Landsat imagery acquired on June 25, on July 2, and on July 11. During August and September 1984, the National Mapping Division, in cooperation with the Water Resources Division, prepared a Landsat image map of the Great Salt Lake and vicinity at 1:125,000 scale from Thematic Mapper data. The four-color image map is printed on the reverse side of the 1974 Great Salt Lake and Vicinity topographic map. In addition to the high lake level, the image map shows the major cultural changes that have taken place within the past 10 years. This project demonstrated that a transitory phenomenon, such as the unusual rise of the Great Salt Lake, can be mapped within a relatively short period of time. With the use of space imagery and the computer processing of digital data, the time required for such mapping can be reduced from the several years of a normal mapping project to a few weeks.

The Geological Survey continues to evaluate side-looking airborne radar imagery for use in geoscience mapping. Twelve controlled 1:250,000-scale quadrangle image mosaics of the Aleutian Islands in Alaska have been printed by screenless lithography and are available with or without updated topographic maps on the reverse side. Thirty-eight 1:250,000-scale radar image mosaics of the Appalachian region from Alabama to Maine are being compiled from data acquired in 1984.

Information Services

The Geological Survey disseminates much of the Nation's earth science information through its Public Inquiries Offices, National Cartographic Information Center offices, and Earth Resources Observation Systems Data Center. The National Mapping Division operates these public access points for the Survey and sells the Survey's books, maps, map-related products, aerial photographs, and digitized cartographic and earth science data on tapes. Survey maps also are sold through a network of authorized dealers, and map information is available from offices in 37 States that are affiliated with the National Cartograhic Information Center.

Information efforts during fiscal year 1984 were concentrated on further implementation of a modern product distribution system, improvement of existing public access offices and services, initiation of a public service announcement program, conversion of State map indexes to a booklet format, and sponsorship of a national tour for the map exhibit *Maps and Minds*.

In the area of product distribution, the existing computer-based system for inventory control was enhanced to include order processing and customer accounting features for the public sale and distribution of the various types of Survey maps and books. Telecommunication facilities linking the major Survey warehouses in Arlington and Alexandria, Virginia, and Denver, Colorado, to the host computer were upgraded to accommodate an increase in the number of terminals required to handle the thousands of orders received each year.

The activities of the Public Inquiries Offices were expanded to meet the need of heightened public interest in earth science information. A new information and sales office was opened in Anchorage, Alaska; facilities and equipment in other offices were upgraded; and intraoffice references were put on microcomputers.

The Public Inquiries Offices also made significant progress in applying the Earth Science Information Network to the dissemination of information. This network is a computer-based system that electronically links the Survey's information offices to various data bases. At present, the network provides access to data bases relating to geographic names, sources of water resources data, news releases of the Geological Survey, status of digital mapping, and bibliographies of geologic and water resources publications. In the future, the Public Inquiries Offices will be able to use the network technology to access information from many additional sources.

The Applications Assistance Facility, located at the National Space Technology Laboratories in Bay St. Louis, Mississippi, has put into operation an annex designed to provide greater capacity for its regularly scheduled cartographic and geographic workshops. The workshop facility contains eight surge-protected microcomputer workstations for hands-on digital demonstrations, a remote information processing system linked to the Earth Resources Observation Systems Data Center in Sioux Falls, South Dakota, and a terminal with access to the Survey's

J. Schubert uses a planetable alidade on a field project in the Alabama Hills area near Lone Pine, California. Mount Whitney is in the background (above the truck grill, to the right of the twin cones).

Earth Science Information Network. Ample work space is provided for 18 to 20 participants. An adjoining multimedia room with full video editing capacities adds to the effectiveness of the facility as a training-public awareness center. The new facility was inaugurated with a 3-day seminar on the new Geological Survey digital cartographic standards, which was attended by faculty and graduate students from six southern universities.

The Applications Assistance Facility, working closely with personnel from each of the field mapping centers, also coordinated a series of five workshops on modern mapping methods for the Department of Transportation's Federal Highway Administration. These workshops emphasized new digital cartographic techniques and introduced participants to the Survey's digital cartographic programs. A series of video training modules illustrating digital techniques was prepared to provide uniformity in presentations at different locations and to build a file of representative digital cartographic applications for use in workshops scheduled in other Federal Highway Administration regions during fiscal year 1985.

The Division initiated a program of brief public service announcements focusing on maps and outdoor safety. An outdoor safety theme was chosen because nearly 1,000 people each year get lost in wilderness areas of national parks and forests. Using the phrase, "Be safe, carry a map," a series of public service announcements were sent to 15 nationally distributed outdoor and sports magazines. Within an 8-month period, more than 3,000 people responded to the published announcements and requested more information. These enquiries were answered with a brochure on how to use a topographic map, a State index of topographic maps, and a list of private map dealers in the requester's local area who could give additional information. On the basis of the success of this initial test, the Division plans to start testing public service announcements on radio and television next year and to expand distribution of the printed announcements.

To show all of the various types of published topographic maps and map products on each State index (up to 30 different map and product lines for some States), the Division is converting its single-sheet map indexes to an index booklet and companion catalog for each State. The new multicolor indexes are designed so as not to need an annual updating; the preparation of the companion one-color catalogs is fully automated so they can be efficiently updated and reissued on an annual basis. When the conversion is fully completed in late 1985, the index-catalog format for each State will help to keep the public and Federal, State, and local government agencies informed of newly published topographic maps and map products as they become available.

In cooperation with the National Geographic Society, the Survey sponsored a major exhibit, *Maps and Minds*, on the history of mapping from prehistoric times to the satellite age. The exhibit focuses on the Federal Government's role in American cartographic history and the role of mapping in the opening of the American West. The colorful 120-panel exhibit is a collection of more than 500 photographic images, with extensive text and captions. *Maps and Minds* is on a 10-site national tour, including stops at science and technology centers and museums in Tampa, Florida, Atlanta, Georgia, St. Paul, Minnesota, Dallas, Texas, and San Francisco, California.

Research, Investigations, and Developments

INVESTIGATION AND ASSESSMENT OF AUTOMATED CARTOGRAPHIC CAPABILITY

For the past several years, the National Mapping Division has been involved in the process of collecting and processing cartographic data in digital form to support the development of a digital cartographic data base. The data base provides basic categories of data for computer-based information and management systems and also provides the framework to streamline the mapping process for preparing revised and derivative map products.

In August 1983, the National Mapping Division and the Defense Mapping Agency established a joint working group to investigate and assess the feasibility of applying automated cartographic techniques to the production of 1:50,000-scale topographic maps from 1:24,000- and 1:25,000-scale quadrangles.

The working group reviewed current production procedures employed by the National Mapping Division in the manual production of these 1:50,000-scale topographic maps, as well as the capabilities of private companies to support the production of these products using digital cartographic techniques.

Upon completion of the initial investigation, the work group determined that it was feasible for private industry to develop the procedures and software to support this production effort. A statement of work was prepared to cover the development and subsequent production of these products and was distributed to private contractors in February 1984. Proposals from interested contractors have been received and on-site demonstrations conducted.

AERIAL PROFILING OF TERRAIN SYSTEM

The Aerial Profiling of Terrain System, under development since 1974, is a precision airborne surveying system capable of measuring elevation profiles across various types of terrain from a relatively light aircraft at flight heights of up to 3,000 feet above the ground. A laser profiler measures the distance from the aircraft to the terrain, an inertial measuring unit continuously monitors the aircraft's position, and a laser tracker updates the position by measuring distances to ground-based reflectors.

Performance evaluation flights were completed in June 1984 with the accumulation of 54 profiles at three different test sites. The data indicate the system does meet the design accuracies of ± ½ foot vertically and ± 2 feet horizontally when tracker updates are acquired at 3-minute intervals. Flight testing is now directed toward developing more efficient system operation and performing application tests for several different earth science programs.

RADAR STUDIES

In 1980, the Geological Survey began a Side-Looking Airborne Radar program as a result of the Congressional request to "begin the use of side-looking airborne radar imagery for topographic and geologic mapping, and geologic resource surveys in promising areas,

In a dry salt bed, J. Hanchett records while L. Lindahl uses electronic distance-measuring equipment during field activities in the Saline Valley area, California, near Death Valley National Monument.

particularly in Alaska." Since the program began, more than 400,000 square miles of radar data have been acquired in the contiguous United States and Alaska for entry into the public domain, and approximately 150,000 square miles are planned for acquisition in fiscal year 1985. In addition, the Survey has supported over 60 studies addressing the geologic, hydrologic, cartographic, and engineering applications of this technology.

Side-looking airborne radar systems contain a transmitter that provides a pulse of microwave energy that is emitted from an antenna. The energy pulse travels to the ground, is reflected, and returns to a receiving antenna. This reflected energy then is collected and used to make an image on film, analogous to the photographic process. Because imaging radar is an active sensor that provides its own source of illumination, imagery can be obtained through clouds and rain, day or night. Therefore, side-looking airborne radar can be used to prepare image-based maps of persistently cloud-covered areas where conventional aerial photography is very difficult to obtain.

High-resolution x-band (3-centimeter) imagery from both real- and synthetic-aperture radar systems was acquired for selected areas of the Alaskan Peninsula. A set of several radar image products of the 1:250,000-scale Ugashik, Alaska, quadrangle is being prepared to provide comparative imagery between the two systems. The set includes four mosaics depicting real- and synthetic-aperture imagery from four different look angles, radar image strips from both systems for stereo viewing, and one radar mosaic overprinted with information from the corresponding topographic map to serve as a shaded relief map with color tints to enhance land and timber areas. The set also will include descriptive text on the geology of the Ugashik area and on the principles of radar imaging.

The all-weather capability of radar also provided the opportunity to obtain cloud-free imagery of the Aleutian Arc in Alaska. The Survey recently published twelve 1:250,000-scale radar image mosaics of the Aleutian Islands. The mosaics were prepared by enlarging and mosaicking the 1:400,000-scale radar image strips and matching the imagery to geodetic control points and map points on the corresponding 1:250,000-scale topographic maps. The topographic maps were published originally in the 1950's and classified as reconnaissance editions in recognition of the technology prevalent at that time. The radar mosaics are printed back-to-back with the corresponding topographic maps, which are updated to show the latest feature names, township and range lines, and locations of offshore leasing tracts. The mosaics and topographic maps are also available separately.

The unique geometric characteristics of radar present certain problems in attempting to merge radar imagery with other image data, such as from Landsat. To better understand the geometry and registration problems inherent in radar data acquired at varying depression angles over steep terrain, a research project is underway to generate a shaded relief image from digital elevation model data processed to simulate the geometry of radar imagery using a variety of radar parameters. Part of the research will include registering digital elevation model data to radar data and correcting the radar image for major relief displacements.

GEOGRAPHIC INFORMATION SYSTEMS DEVELOPMENT

Geographic information systems are emerging as a new tool for a wide range of scientific disciplines. These systems provide the capability to combine statistical and tabular data with map information from digital data bases. The power and speed of the computer then can be applied to manipulate and analyze these data. Techniques of computer graphics can be utilized to display the data and the results of the analyses. Geographic information systems provide rapid and powerful analytical techniques, combined with the ability to automatically produce the results on maps, and will be of major benefit to many users, especially natural resource planners and land managers.

The central role of map information in geographic information systems has led the National Mapping Division to undertake the development and application of these systems for diverse uses. Among the objectives of the present program are as follows:

- To ensure a high degree of diversity and flexibility in the Division's ability to handle, process, and analyze vector and raster formatted data to be responsive to a wide variety of Division, Bureau, and Department requirements.
- To maintain, improve, and utilize the Department's Map Overlay and Statistical System to support information requirements for resource management and planning.
- To define, develop, implement, and operate an integrated information system that can handle, process, and analyze data about land ownership and about mineral, energy, water, soil, forest, range, and wildlife resources on a national scale to support Department policy decisions.
- To provide leadership and coordination between Federal agencies and Department bureaus in development and application of digital cartographic data and geographic information systems.

REMOTE INFORMATION PROCESSING SYSTEM

In 1980, the Earth Resources Observation Systems Data Center initiated development of a Remote Information Processing Station capable of generating a continuous-tone color display. The station was connected to a host minicomputer through a standard telephone line and was configured so that image processing software could be developed efficiently for stand-alone operation. Experimental software was written to demonstrate the system's unique capabilities. Highlights of the early project work included the design and assembly of three prototype units, development of a package of conversational applications software containing more than 40 image processing functions, and development of a prototype communications protocol with provisions for image data compression and error detection-correction.

In early 1982, specifications were written for competitive procurement of 6 to 12 systems to be used in technique development, training, and applications project activities. Later, the total number of systems was increased to 18.

In April 1983, a plan was drafted for the transition of the system from research to operational support. In January 1984, the first users conference was held for 30 users to exchange ideas, discuss applications, and make recommendations. By this time, the total number of systems in the field (prototype and operational) had increased to about 80.

Highlights of the transition project included acceptance, checkout, and installation of 11 systems at user sites; release of 69 applications programs, 100 support routines, and more than 500 pages of documentation; and definition of standard products and services.

In July 1984, software was released which included new routines for performing topographic analysis and display of digital elevation model data products. Also released was software for two-way file transfer of binary image data from the Remote Information Processing System to the VAX and HP3000 systems. With the increased emphasis on operational development, applications software is now beginning to appear from a larger user community which has learned to program the machine for specialized applications.

IMAGE MAP RESEARCH

The Survey has developed experimental image maps from the Landsat program at the 1:250,000 (from the multispectral scanner) and the 1:100,000 scale (from the Thematic Mapper). During 1984, this research was continued and resulted in two image products of the Washington, D.C., area, both derived from the Thematic Mapper. The first was a 1:100,000-scale map which utilized the blue (band 1), red (band 3), and near infrared (band 5) printed in yellow, magenta, and cyan, respectively.

The second product was the *Landsat Thematic Mapper (TM) Color Combina-*

tions, *Washington, D.C., and Vicinity*, published as Geological Survey Miscellaneous Investigation 1616. This report graphically illustrated the various color combinations and permutations that are possible from the six spectral bands selected for this project. The report quantitatively described the rationale behind spectral band selection to present the maximum information for a given scene.

One significant finding of this research is the establishment of a picture-element (pixel)-to-scale relationship criterion of 3.3 pixels per millimeter at map scale. This means that the 75- to 80-meter pixels of the Landsat multispectral scanner are suitable for 1:250,000-scale image mapping. The 30-meter pixels of the Thematic Mapper are suitable for 1:100,000 scale, and 15-meter pixels are needed for 1:50,000 scale.

ORBITAL MAPPING SYSTEM

During the past several years, a space system for mapping the Earth's surface topography has been defined. This system, called Mapsat, was patented in 1982. During 1983 and 1984, the International Society for Photogrammetry and Remote Sensing activated a committee to define an optimum system for mapping from space and requested Geological Survey personnel to organize and chair the committee. The committee's report, *Acquisition and Processing of Space Data for Mapping Purposes*, was submitted to the International Society for Photogrammetry and Remote Sensing during their XV Congress in Rio de Janeiro, Brazil, in June 1984. The report was accepted and is being forwarded to the various space agencies and the 73 national societies that make up the international society.

Geologic Investigations

MISSION AND OUTLOOK

During fiscal year 1984, the Geologic Division continued its programs to assess energy and mineral resources onshore and offshore, to identify and investigate geologic hazards, and to determine the Nation's geologic framework, the geologic processes that have shaped it, and their relation to long-term climatic changes.

The articles in this chapter of the *Yearbook* describe some of the most significant accomplishments of the Geologic Division during fiscal year 1984. We believe that these articles, while representing only a select few of the activities of the Division, show how basic geologic research simultaneously provides the opportunity for new developments in the geosciences and provides the basic information needed to conduct missions that are central to the national welfare.

MAJOR PROGRAMS

The Geologic Division program is presented to Congress under five major program headings. A discussion of accomplishments under these subactivities during this last fiscal year follows.

Geologic Hazards Surveys

As a result of earthquake prediction research of the U.S. Geological Survey, the location and the magnitude of the 1984 Morgan Hill, California, earthquake were anticipated successfully. In 1980, the Geological Survey had forecast that an earthquake comparable to the 1979 Coyote Lake, California, earthquake (magnitude 5.9) might occur on the Calaveras fault in the area near Morgan Hill. Geological Survey studies had suggested that complexities (bends and offsets) in the trace of the Calaveras fault control where earthquakes start and that these barriers, when broken, produce large shocks.

The Geological Survey and the Utah Geological and Mineral Survey are conducting a joint Federal-State earthquake hazards assessment of the Salt Lake City-Wasatch Front corridor. The 3-year study began in fiscal year 1984 and will establish the earthquake potential of the Wasatch fault zone, which is inhabited by 85 percent of Utah's population.

Landslides again were triggered by rapid melting of record mountain snowpacks in April and May 1984 and caused widespread damage in Utah along the Wasatch Front and on the Wasatch Plateau. Geological Survey landslide specialists assisted the Utah Geological and Mineral Survey during the emergencies in the search for and the identification of landslides that posed an immediate threat to public safety.

Short-term warning and monitoring of each of the numerous phases (24 as of September 1984) of the long-lived eruption of Kilauea Volcano in Hawaii that began in January 1983 continued in fiscal year 1984 under the Volcano Hazards Program. The March 25 to April 15, 1984, eruption of Mauna Loa volcano in Hawaii was forecast successfully in late 1983 by the Geological Survey. The forecast was based on monitoring results that showed high seismic activitiy and active deformation taking place near the summit of Mauna Loa.

A computer-enhanced monitoring system for Spirit Lake and other debris-dammed lakes near Mount St. Helens was installed in fiscal year 1984. The system utilizes satellite and radiotelemetry units for transmitting realtime water-level data for immediate warning of any failure of the debris dams.

Land-Resource Surveys

During fiscal year 1984, State geologic maps for Wyoming and Massachusetts were published or approved for publication. These maps are the syntheses of hundreds of man years of research under the Geologic Framework Program and join the Kentucky State geologic map as indispensable tools for mineral- and energy-resource studies, regional tectonic syntheses, and as "state-of-the-art" models for other State map compilations.

Research on the "accreted terrane" theory resulted in the completion of maps showing the lithotectonic terranes (microcontinents) of western North America including map explanations and descriptive pamphlets. This study incorporated geologic mapping, paleontologic, paleomagnetic, and isotopic research to treat the areal extent, characterization, and interrelation of more than 200 terranes that were accreted to western North America during the past 250 million years. As an example, studies of certain fossil groups found in rocks from one of these terranes suggest that it was probably once attached to what is now Eurasia or Indonesia. Measurement of the magnetic properties of rocks in many of the terranes have enabled geologists to calculate the latitude and longitude at which the rock formed; in many cases, the calculated location is thousands of miles from where the terrane currently is located. Preparation of these maps resulted from international collaboration of Geological Survey personnel with scientists from Mexico and Canada.

Continued stratigraphic studies of deep sea cores, cores from lakes, and terrestrial outcrops under the Climate Program are building a more complete understanding of climatic events. Identification of diverse paleoclimates that existed over the last 1 or 2 million years is being aided by comparing dated volcanic ash layers from onshore sites with those collected from deep-sea cores. This information, combined with oxygen-isotope analyses of microfossils found in the marine deposits, has been used to determine temperatures and climatic conditions through the time periods dated by the ashes. Of particular importance are several widespread, well-dated ash beds found in a 990-foot core at Tulelake in northeastern California. These ashes were formed by volcanic eruptions in the Cascade Range of the Northwestern United States, the Yellowstone area of western Wyoming, and the Sonoma volcanic field in the central Coast Range of California. Several of the ash layers have been found in marine deposits west of Tulelake and in deep-sea cores.

Mineral-Resource Surveys

Emphasis on the location of additional domestic strategic and critical mineral deposits, including the development of exploration and assessment techniques, continued to have a high priority in fiscal year 1984. Such investigations led to the recognition of a close association between concordant tourmaline-rich rocks (tourmalinites) and stratabound deposits of base metals, gold, tungsten, cobalt, and tin. This association demonstrates that tourmaline can be used as a pathfinder for these deposits.

A multidisciplinary study was initiated to assess the mineral potential of the Mesozoic basins in the Eastern United States and the buried crystalline basement of the midcontinent. Geologic theory predicts that these two relatively unexplored terranes have high potential for discoveries of chromium, cobalt, platinum, nickel, gold, and other strategic and critical minerals.

Estimates of world bauxite resources have been updated by the Geological Survey, in cooperation with the U.S. Bureau of Mines. Bauxite is the primary ore mineral of aluminum. World bauxite reserves are estimated to be 21 billion tons. Total world bauxite resources (reserves plus subeconomic and undiscovered resources) are estimated to be 55 to 75 billion tons, an increase of 5 to 25 billion tons over the previous estimate of a maximum of 50 billion tons.

Preliminary results of mineral-resource assessments under the Conterminous United States Mineral Assessment Program (CUSMAP) in the Sherbrooke-Lewiston area of Vermont, New Hampshire, and Maine were presented at a public meeting in September 1984. New CUSMAP regional mineral resource assessments were initiated in the Joplin area, Missouri-Kansas, the Harrison area, Arkansas-Missouri, the Roseau-International Falls area, Minnesota, and the Redding area, California.

Mineral-resource assessments of twenty-nine 1- x 2-degree quadrangles (an area ranging from 4,580 to 8,669 square miles) in Alaska have been completed to date. Projected plans for the Alaska Mineral Resource Assessment Program (AMRAP) are to complete a total of 100 quadrangles by the year 2000. Major mineral deposit discoveries that have been made under AMRAP include copper, zinc, tin, tungsten, lead, silver, and other base metals.

During fiscal year 1984, continuing mineral resource assessments of roadless areas of the U.S. Forest Service revealed a moderate potential for volcanogenic massive sulfide, and possibly gold, deposits. This discovery was made in the Bread Loaf Roadless Area in the Green Mountains of Vermont, a region without previously known mineral occurrences.

Energy Geologic Surveys

An exploration technique for the discovery of very young uranium-rich peat deposits has been developed and tested in Stevens County, Washington, where uranium in peat is being mined for the first time in the United States. The technique involves the preparation of maps showing suitability for the occurrence of uranium. These are made by synthesizing selected data from bedrock, structural, and surficial geology combined with data from soil and vegetation types and with hydrological data.

During fiscal year 1984, the Department of Energy and the Geological Survey successfully accomplished the transfer to the Survey of the data that were collected, and the analyses that were conducted, under the Department of Energy's National Uranium Resource Evaluation (NURE) Program. The Survey also concluded an agreement with the Energy Information Agency to provide up-to-date estimates of the Nation's uranium resources based on research investigations, such as the discovery of the uranium potential in the peat deposits in Stevens County, Washington. The Survey has integrated the NURE information into its ongoing programs to make earth science data available to the public.

Program planning and methodology development for compiling energy-resource maps for all federally owned land were initiated in fiscal year 1984 to supplement the oil and gas potential maps for wilderness lands in 11 Western States that were published earlier.

The Coal Investigations Program continues to place a high priority on coal-quality research and on making the National Coal Resources Data System (NCRDS) more accessible and responsive to the needs of Federal, State, and local land managers. A series of presentations to demonstrate the type of graphs, maps, and coal-quality data available through NCRDS is being planned for fiscal year 1985. Additional information on the coal-quality research of the Geological Survey is found elsewhere in this chapter.

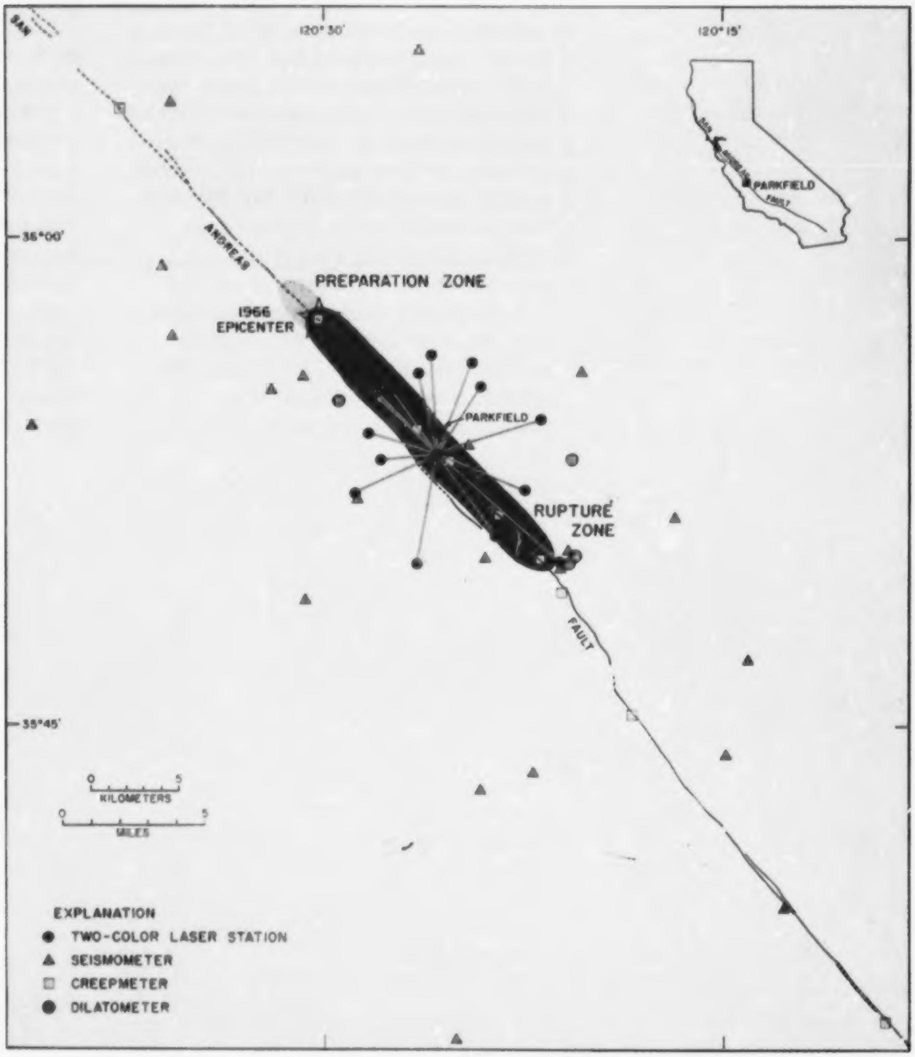
Offshore Geologic Surveys

Initial studies in support of the President's proclamation of the "Exclusive Economic Zone" (EEZ) were underway in fiscal year 1984, including the completion of "Operation Deep Sweep," a cruise that included surveys "from pole to pole." Additional information on this cruise is found elsewhere in this chapter. A detailed plan for preliminary sonar image and multichannel geophysical surveys and bottom sampling of the entire 6 million square miles of the frontier EEZ within a 10-year period are being developed. This research will provide the "road maps" for the development of the vast energy and strategic and critical mineral resources of the EEZ, which is truly America's last frontier.

Research in Earthquake Prediction— The Parkfield Prediction Experiment

The 15-mile-long Parkfield, California, section of the San Andreas fault is the best understood earthquake source region in the world. Moderate-sized earthquakes of local magnitude (M_L) 5¾ occurred at Parkfield in 1881, 1901, 1922, 1934, and 1966. The only exception to an approximate 21- to 22-year recurrence time is the 1934 shock. The 44 years between 1922 and 1966 is just twice the usual time between the shocks. Thus, the Parkfield earthquake in 1966 reestablished the regular timing pattern of the Parkfield earthquakes. If the next Parkfield earthquake conforms to the pattern, it will occur in the next few years, most likely in 1987 or 1988.

In addition to the predictable 22 years between shocks, Parkfield earthquakes share remarkably similar, or characteristic, features. These similar features—magnitude, length, location of rupture along the San Andreas fault (rupture zone), and epicenter—define the characteristic Parkfield earthquake. The concept of a characteristic earthquake with predictable features means that the design of an earthquake-prediction experiment can be tailored to these specific characteristic features. Because the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● TWO-COLOR LASER STATION
▲ SEISMOMETER
☐ CREEPMETER
● DILATOMETER

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tained in the Parkfield area).

expected recurrence of the next Parkfield earthquake is near and the historic Parkfield earthquakes have been so similar, Parkfield provides a unique opportunity to prepare an experiment to observe the final stages of the process leading up to the earthquake.

The observations and accounts available for the last characteristic Parkfield earthquake, on June 28, 1966, serve as a template for anticipating the features of the next Parkfield earthquake. In the 6 months before June 28, all earthquakes near Parkfield occurred on the San Andreas fault northwest of the rupture zone. The foreshocks, smaller earthquakes occurring near the rupture zone shortly before the main shock, occurred within a mile or so of the main shock epicenter, which was located at the northwest end of the rupture zone; this area has been named the "preparation zone." A similar foreshock and characteristic earthquake pattern occurred in 1934 within this preparation zone. Although many small earthquakes occur on the San Andreas fault northwest of the rupture zone, earthquakes within the critical preparation zone are infrequent. The U.S. Geological Survey has established a very dense network of seismograph stations near Parkfield to monitor the seismicity within and near the preparation zone; any increase in seismic activity will be scrutinized closely.

Some geologists think that earthquakes are preceded by fault creep (movement on a fault without detectable earthquakes). An irrigation pipeline that crosses the San Andreas fault near Parkfield broke without detectable earthquakes about 9 hours before the 1966 earthquake. Unfortunately, the history of the movement that resulted in the broken pipe is unknown; although geologists infer 1 to 2 feet of displacement from the broken pipe, perhaps only a very small part of the displacement occurred in the days and weeks just before the 1966 earthquake. Also, fresh cracks of uncertain origin were observed along the San Andreas fault 12 days before the 1966 earthquake. The broken pipeline and the fresh cracks are consistent with fault creep near Parkfield just before the characteristic earthquake in 1966.

If significant and unusual fault creep precedes the next characteristic Parkfield earthquake, the sophisticated, sensitive devices deployed near Parkfield should record it. Surface fault movement is monitored continuously by several creepmeters, 30-foot-long devices that cross the fault trace. Also, approximately 2- to 5-mile-long lines of sight which cross the fault will be measured each night on a two-color laser distance-measuring geodimeter that can resolve changes of less than one-half of an inch over a distance of 6 miles. Volumetric strainmeters, balloon-like instruments installed in boreholes, will measure minute changes in strain. The two-color laser geodimeter and the orehole strainmeter observations hould corroborate changes in seismicity nd fault creep. On a more fundamental asis, they will define the deformation ocess leading up to the next aracteristic Parkfield earthquake.

The Parkfield, California, earthquake ediction experiment is an important ement of the Geological Survey's earthquake prediction strategy for the United States. The Parkfield experiment is providing important experience in the design and operation of strain-monitoring instruments that ultimately may be adapted for use in a prototype earthquake-prediction network. An understanding of the earthquake process at Parkfield may yield data fundamental to the successful design of earthquake prediction strategies for southern California and other earthquake-prone areas of the United States.

MAGNITUDE

Earthquake magnitude is a measure of the strength of an earthquake, or the strain energy released by it, as calculated from the instrumental record made by the event on a calibrated seismograph. In 1935, seismologist Charles F. Richter first defined local magnitude (M_L), or Richter magnitude, as the logarithm (to the base 10) of the amplitude in micrometers of the maximum amplitude of seismic waves that would be observed on a standard torsion seismograph at a distance of about 60 miles from the epicenter. The seismic waves used for local magnitude have periods ranging from approximately 0.1 to 2 seconds, equivalent to a wavelength of 1,000 feet to 3.8 miles.

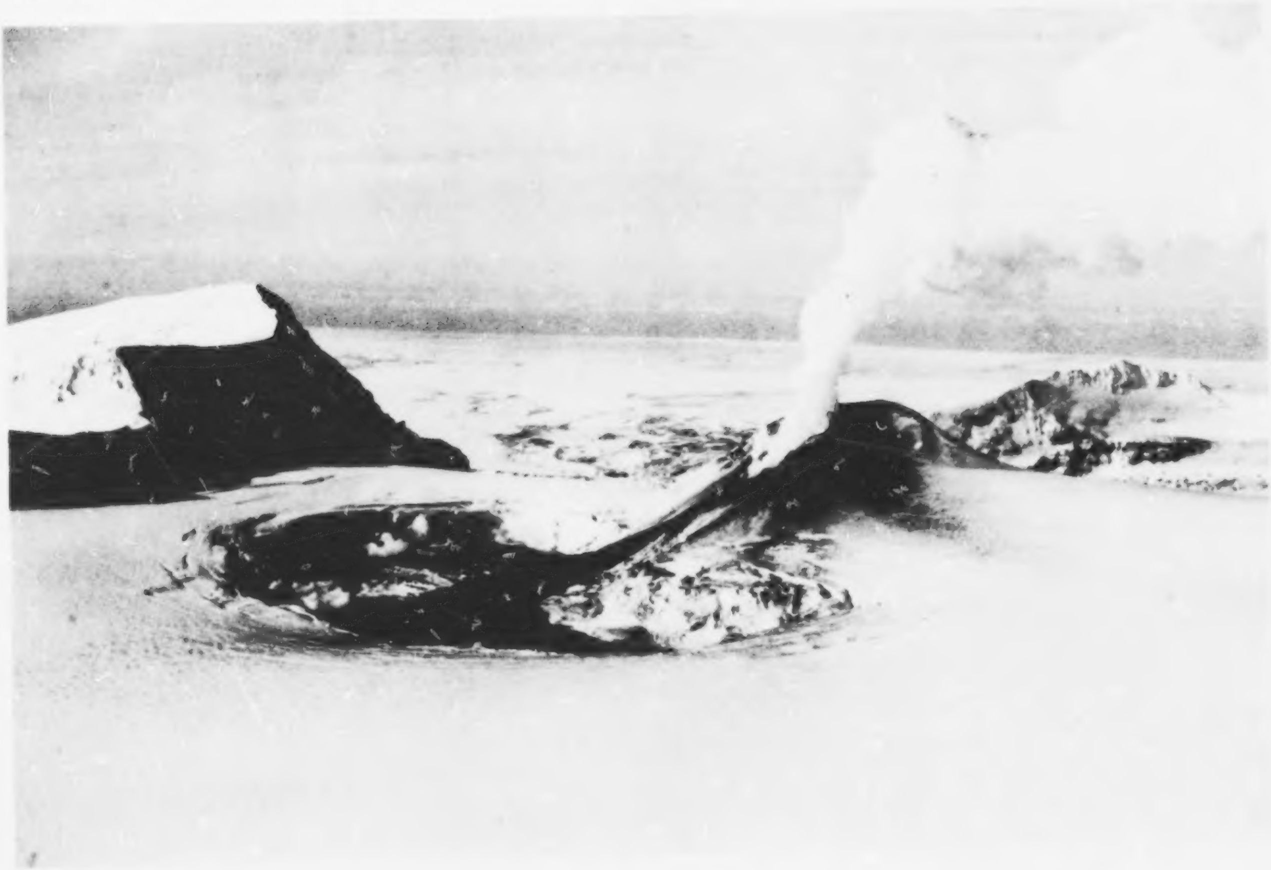
The 1984 Eruption of Mauna Loa Volcano

March 30, 1984, was an historic day for the United States and a busy one for the U.S. Geological Survey—four volcanoes were in simultaneous eruption in the United States! About 50 volcanoes are active in the United States (those known to have erupted in historic times), but, until this date, no more than two of them had been known to erupt on the same day.

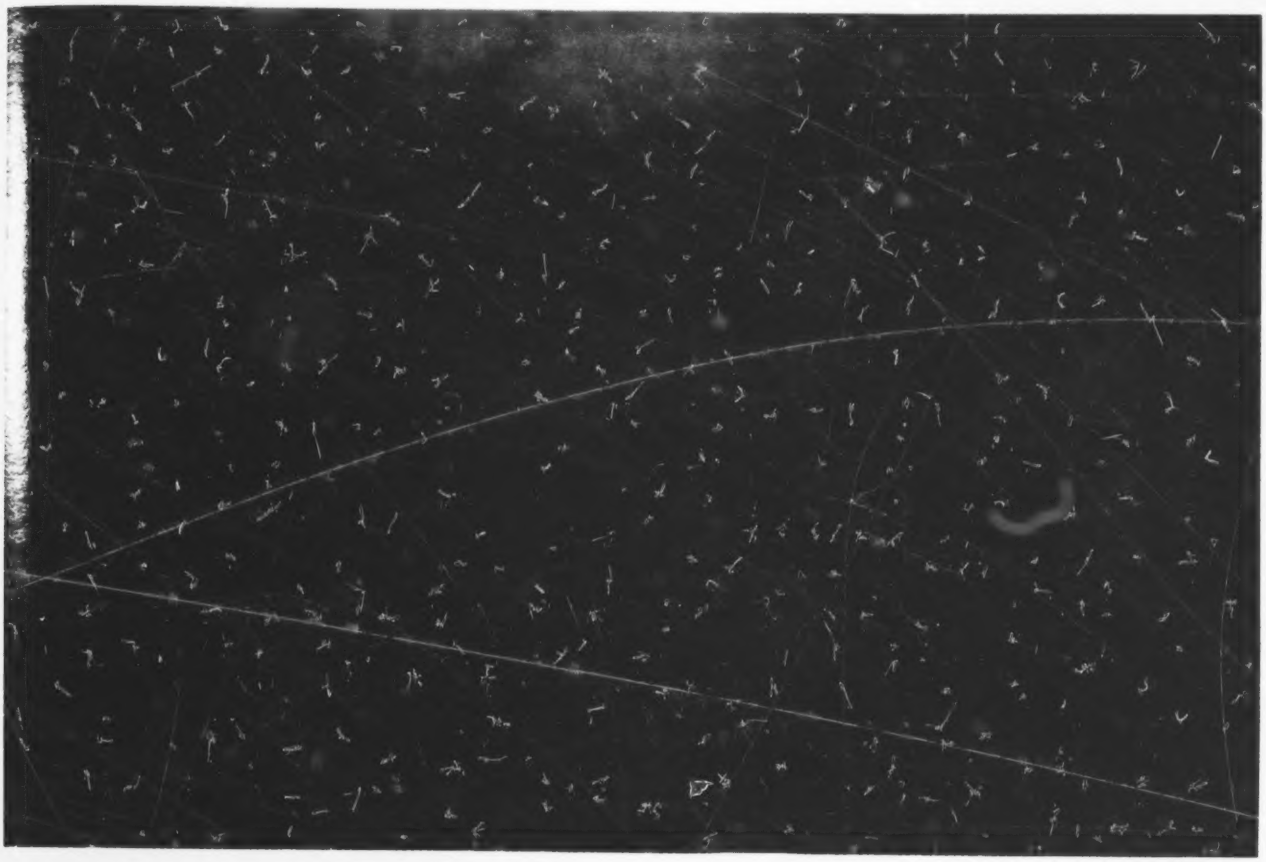
The circumstances leading up to this historic day began in June 1983, when Veniaminov Volcano, on the Alaskan Peninsula, began a series of eruptions, which continued at a low level into spring 1984. Then, on March 25, Mauna Loa Volcano, on the island of Hawaii, began a long-expected major eruption. This was followed on March 29 by the beginning of another eruptive phase at Washington State's Mount St. Helens Volcano, which has been active intermittently since March 1980. The final actor in this volcanic drama burst into action early on the morning of March 30 as Kilauea Volcano, also on the island of Hawaii and frequently active since January 1983, began a short episode of high fountaining.

So, on this date, U.S. Geological Survey field crews were at work at three volcanoes—in the tropical rain forest of Kilauea, high above the timberline on Mauna Loa, and within the snow-covered crater of Mount St. Helens. Poor weather on that day prevented access to the remote, largely ice-covered Veniaminov, although villagers 20 miles away reported that a steam cloud rose to 7,500 feet above the volcano.

The largest of these four eruptions, and the one of greatest concern to public safety, was that of Mauna Loa, the largest volcano on Earth. The eruption, which began suddenly at 1:30 a.m. on March 25, climaxed 10 years of increasing seismicity and accompanying inflation of the volcano. This long period of premonitory activity



Veniaminof Volcano in eruption, January 1984. The lava flow down the volcano's south flank has melted a large pit in the surrounding glacier ice. (U.S. Geological Survey photograph by T. P. Miller.)



Mauna Loa's "curtain of fire" advances in en echelon steps down the upper northeast rift zone early on the morning of March 25. (U.S. Geological Survey photograph by J. D. Griggs.)

Mount St. Helens Volcano in eruption, March 29, 1984. *The fresh avalanche from the central dome, which overlies the snowfield, fell that morning and hearalded the beginning of this eruption.* (U.S. Geological Survey photograph by Lyn Topinka.)

had allowed detailed monitoring by Geological Survey scientists from the Hawaiian Volcano Observatory (HVO), who were concerned by the threat posed to the city of Hilo, located at Mauna Loa's base. Forecasts of an impending eruption were published in 1983, stating that an eruption was likely within "the next one or two years."

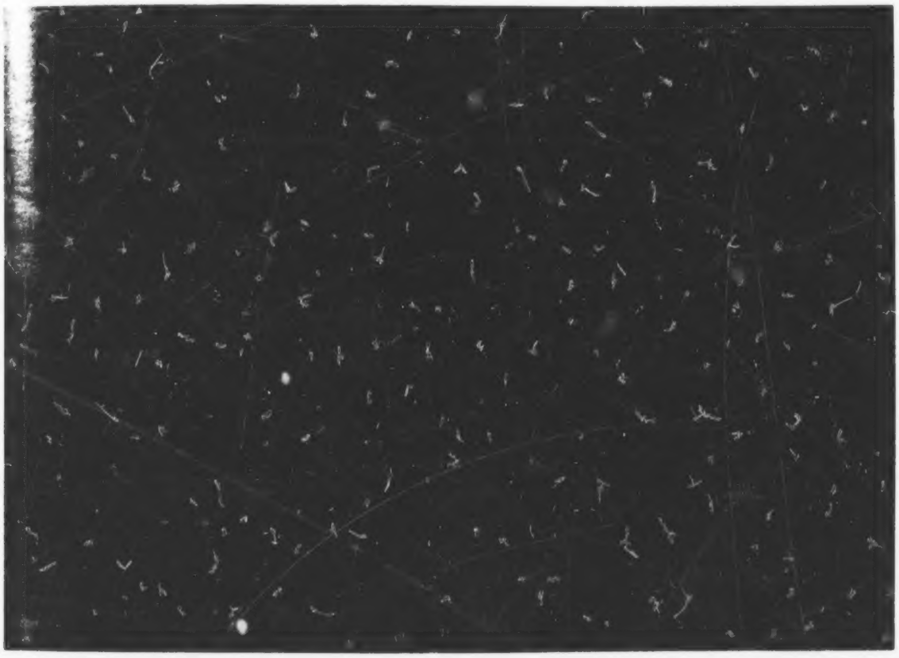
The eruption began within Mauna Loa's summit crater (Mokuaweoweo), at the 13,000-foot elevation but eruptive fissures quickly migrated out of the crater as a subterranean dike was injected down the northeast rift zone. Where this dike reached the surface, lava fountains (Mauna Loa's celebrated "curtains of fire") extended eastward

Kilauea Volcano in eruption, March 30, 1984. The lava fountains within the spatter cone (Pu'u O) are about 300 feet high. (U.S. Geological Survey photograph by E. W. Wolfe.)

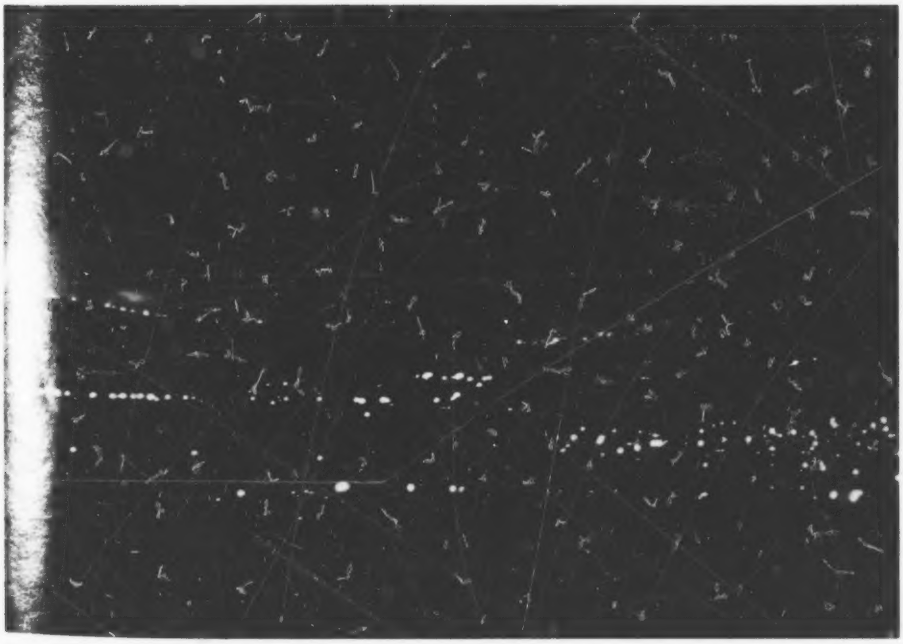
Hawaiian Volcano Observatory geologists at lava fountains on Mauna Loa. Helicopters provided access to remote areas of the eruption and were essential for safety. (U.S. Geological Survey photograph by R. B. Moore.)

along en echelon fractures. As new fountains opened downrift, ones higher upslope shut down.

By nightfall, the principal eruptive vents were located near the 9,400-foot elevation, over 12 miles from the initial summit outbreak, in a mile-long zone that was to feed lava flows to the east for the next 3 weeks. These vents erupted at very high rates (producing over 1 million cubic yards of frothy lava per hour!), and lava flows moved downslope very quickly. Vital high voltage powerlines were cut early on March 26, and a large prison complex was threatened on that first day, but those flows slowed dramatically because most of the erupted lava fed a narrow flow that moved rapidly to the northeast. This flow moved 9 miles in the first 24 hours and, by March 29, had travelled over 15 miles to the



Aerial view of lava rivers below the 9,400-foot vents. Lava stream filling channel on March 26. U.S. Geological Survey scientists in the lower left corner give scale. (U.S. Geological Survey photograph by J. D. Griggs.)



Night view of lava flow advancing on Hilo, showing the city lights in the foreground and the flow in the background, March 27. The flow is actually about 10 miles from the outskirts of Hilo at this time. (Photograph by R. M. Sasaki.)

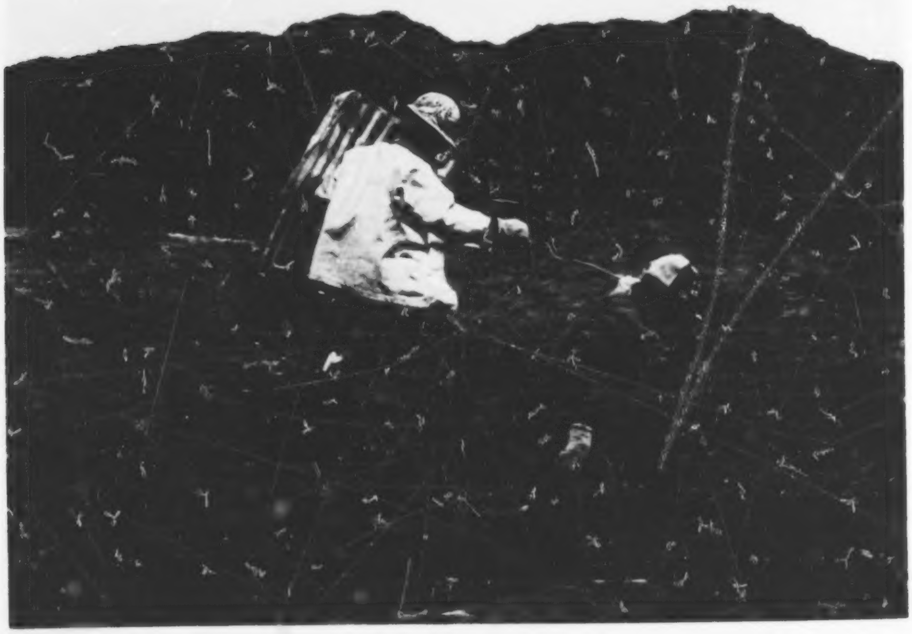
3,000-foot elevation, destroying several square miles of native rain forest and moving to within 5 miles of the nearest homes on the outskirts of Hilo. Public concern mounted within that city, and HVO scientists continued to maintain round-the-clock surveillance.

Temperatures of the molten lava were measured repeatedly during the eruption because temperature changes would indicate changes in lava composition and fluidity, which could cause significant changes in the style and potential hazard of the eruption. Lava temperatures remained fairly constant during the eruption, around 2,080 degrees Fahrenheit, which is relatively "cool" for Hawaiian lavas.

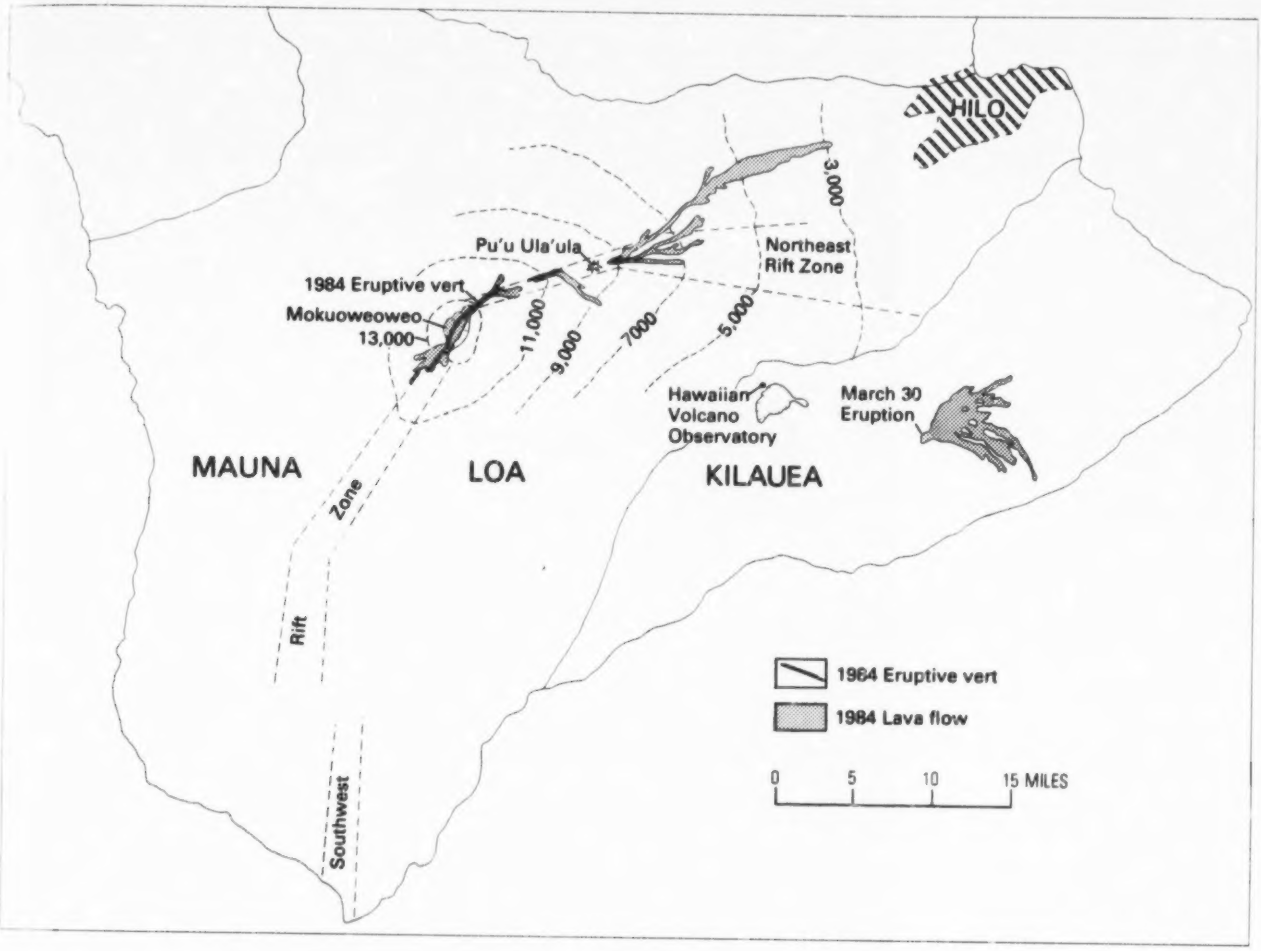
On March 29, a levee of the principal flow channel collapsed at the 5,700-foot elevation, 8 miles upslope from the flow front that was threatening Hilo. Lava was diverted northward at this point to form a second flow parallel to the first, and most of the supply to the initial lava flow was cut off. This second flow also moved rapidly downslope at first but began to slow and did not overtake the first flow until April 4. A second channel collapse and diversion occurred at 6,800 feet on April 5, and a third flow headed rapidly downslope north of the others.

This flow moved only a short distance, however, as the rate of lava extrusion at the 9,400-foot vents began to decrease slightly, the lava feeding the flows appeared to become steadily more viscous, and numerous channel blockages and levee collapses occurred further and further upslope. This completely cut off lava being supplied to the lower flow fronts, easing the threat to Hilo. By April 14 no active lava flows extended more than a mile from the 9,400-foot vents, and the eruption ended on April 15.

About 250 million cubic yards of lava were erupted by Mauna Loa during this eruption, which buried about 12 square miles of the volcano's surface. This was the first eruption of Mauna Loa for which detailed monitoring was possible, and much more has been learned during this eruption than in all previous historic eruptions combined. Geological Survey crews spent the remainder of 1984 compiling eruption data and making detailed field observations of what had actually transpired as well as continuing studies of ongoing Kilauea activity. This information will be used to refine our understanding of Mauna Loa and to provide more acurate eruption predictions in the future at this and at similar volcanoes.



Geologists measuring lava temperatures alongside a lava river. The intense heat (over 2,000 degrees Fahrenheit) requires use of heat shields and protective clothing. (U.S. Geological Survey photograph by T. A. Duggan.)


HILO
3,000
Pu'u Ula'ula
Northeast
Rift Zone
1984 Eruptive vert
Mokuoweoweo
13,000
11,000
9,000
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5,000
Hawaiian
Volcano
Observatory
March 30
Eruption
MAUNA
LOA
KILAUEA
Zone
Rift
Southwest
1984 Eruptive vert
1984 Lava flow
0
5
10
15 MILES

Map showing eruptive vents, lava flow distribution, and relation to Hilo.

STATUS OF U.S. VOLCANOES, AS OF DECEMBER 19, 1984

- Mauna Loa volcano has been in repose since its March–April 1984 eruption. Currently, no significant changes have occurred in summit tilt or seismicity.
- Veniaminov erupted as an ashcloud on November 29, 1984, interrupting a 7-month period of relative quiescence.
- The most recent dome-building eruption at Mount St. Helens occurred between September 9 and 11, 1984, adding a new lobe to the crater dome. As lava was intruded into the dome, it caused remarkably rapid dome deformation.
- Phase 28 of Kilauea's east-rift eruption took place from December 3 to 4, 1984. Harmonic tremor remains at high background levels, suggesting that a 29th phase is likely.

Sulphur Lava Lakes on Jupiter's Moon Io

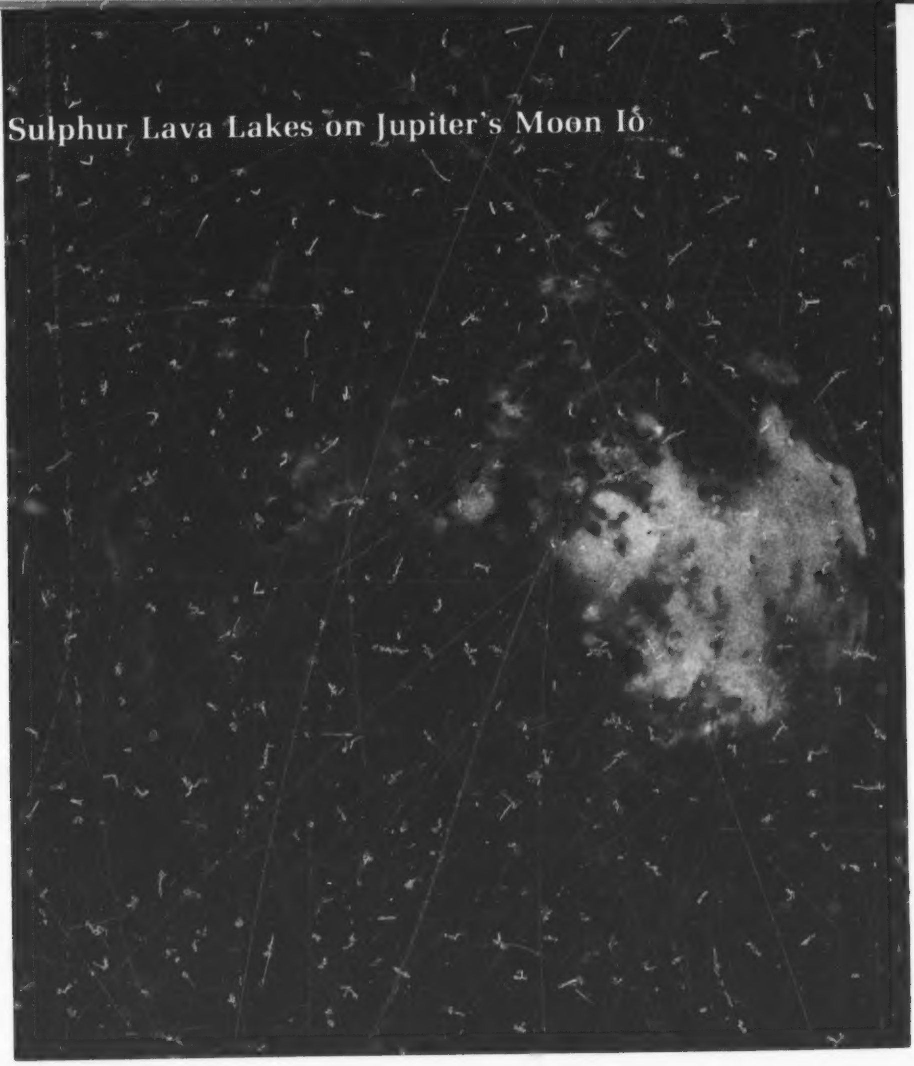


Figure 1. *Voyager 1 full hemisphere color image of Io, the volcanically active moon of Jupiter; arrow indicates the location of the Loki Patera volcanic vent feature shown in figure 3.*

Io is a strange and facinating world. Tidal heating caused by the gravitational pulls of Jupiter and the other large Jovian moons result in Io's having the greatest volcanic activity and heat flow that is known in the solar system today (fig. 1). The average heat flow from its surface is about 19 times greater than that of the Earth and 50 times greater than that of the Moon. How is this tremendous amount of energy carried from within the moon to the surface of Io? Research by scientists from the U.S. Geological Survey and the Jet Propulsion Laboratory in Pasadena, California, supported by funding from the National Aeronautics and Space Administration (NASA), leads them to believe that the heat is transferred primarily through lava lakes composed of liquid sulfur. The studies by these scientists are based on a continuing analysis of the data returned by the Voyager spacecraft and on new data gathered at NASA's Infrared Telescope Facility atop Mauna Kea Volcano in Hawaii.

Seven hot spots on Io were located by the infrared spectrometer on the Voyager 1 spacecraft, and all correspond to relatively dark features on the moon's surface, much darker than the average reflectivity of the surface as a whole. These dark features make up only about one-tenth of 1 percent of the total surface area of Io, but they coincide with at least part of the seven hot spots seen by the Voyager infrared spectrometer. Earth-based observations from the Infrared Telescope Facility have enabled scientists to map the heat from the hot spots as Io rotates, so tha the heat measured when the moon is in a certain position can be compared with the amount of dark areas showing at that same position (fig. 2). The comparison shows that at any given position during rotation, the heat is greatest when the proportion of viable dark areas is greatest (fig. 2). If these dark features are assigned temperatures ranging from 242 degrees to 350 degrees Fahrenheit (appropriate for liquid sulfur), then the calculated heat is consistent with the Earth-based measurements. Furthermore, the albedos relative ability to reflect light) and colors of the dark features match the reflectance spectra of liquid sulfur (fig. 3). Where high-resolution images are available, many of these dark features have characteristics suggestive of lava lakes, such as islands, floating debris, and chilled crusts (fig. 4). The most energetic of these dark features has been named Loki Patera. These probable lava lakes may be efficient convecting systems for the transfer of tidally generated heat to the surface, where the energy is radiated into space.

The stage is now set for an exciting scientific mission when NASA's Galileo orbiter spacecraft arrives at Jupiter in 1989. After delivering a probe into the Jovian atmosphere, the spacecraft will spend several years in orbital tour of the Jovian system. The Galileo Solid State Imaging Experiment, involving several Geological Survey scientists, will record changes in Io's appearance since Voyager and may even produce movies of active eruptions. Also on board will

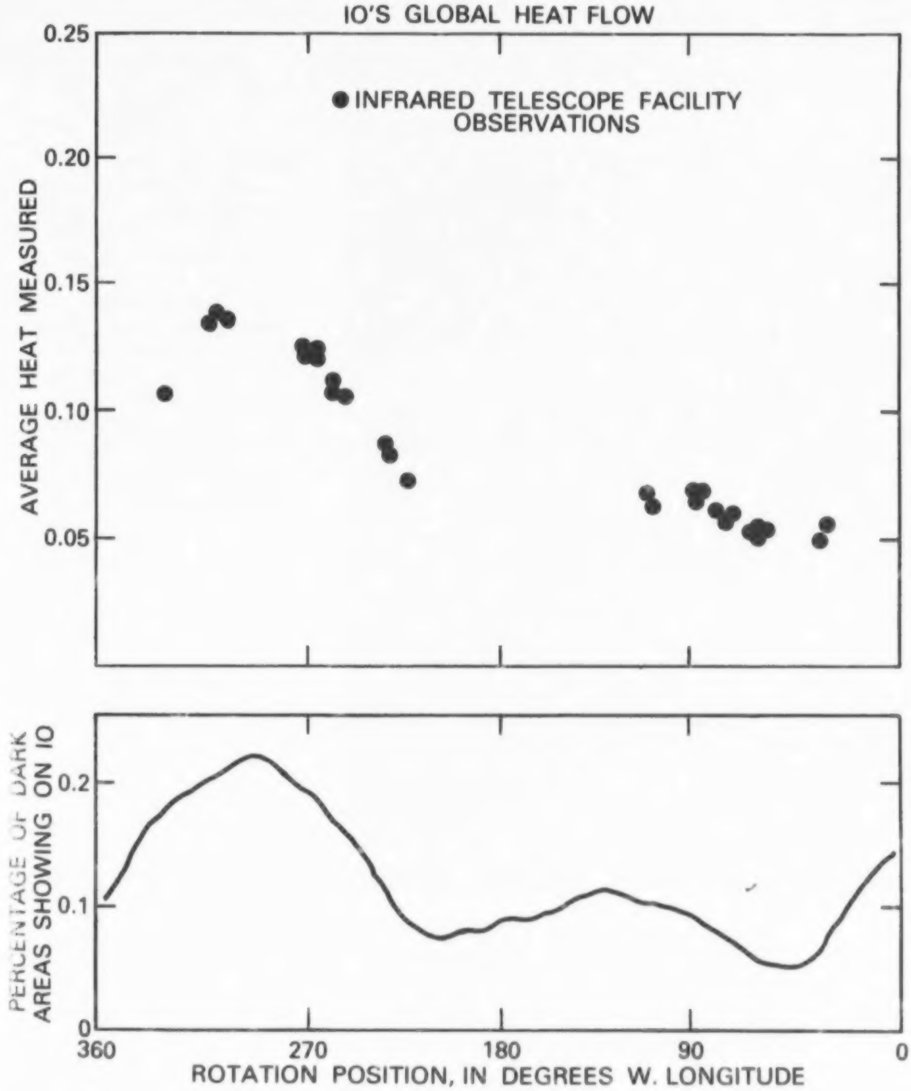


Figure 2. *Ground-based measurements of Io's heat flux made as the moon rotates (top) coincide with the concentration of dark features exposed at the same rotation position (bottom). Note the similar form of the two graphs; where the highest heat value is measured, the greatest percentage of dark areas is showing.*

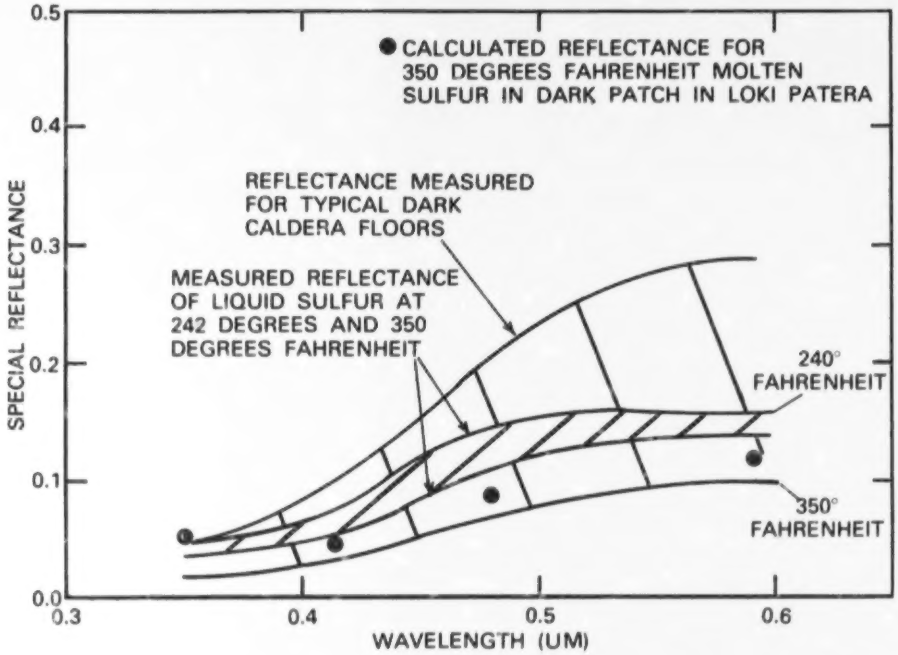


Figure 3. *The spectral reflectance of liquid sulfur closely matches that of many of the dark features on Io. The filled circles are values for the dark patch in the lower left of Loki Patera (fig. 4).*

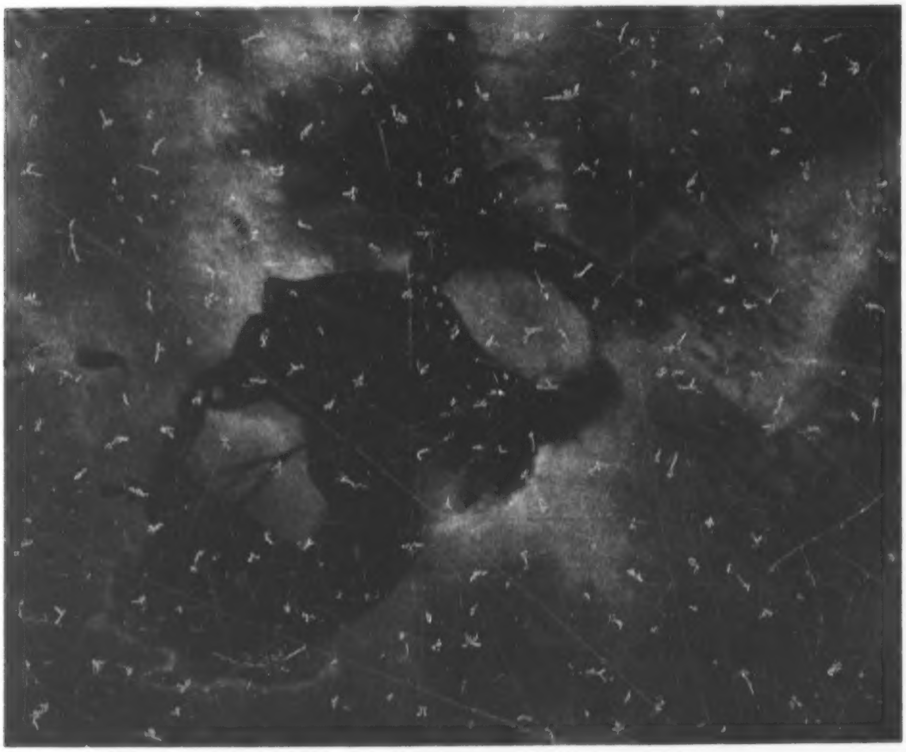


Figure 4. *This feature, named Loki Patera, was the most energetic hot spot detected by Voyager 1. When this image was acquired, volcanic plumes driven by sulfur dioxide gas were erupting from both ends of the narrow linear fissure (curved arrows). Note the large chilled crust islands and floating debris within the 102-mile-diameter black lake of suspected molten sulfur (straight arrow).*

be a new class of instrument, the Galileo Near Infrared Mapping Spectrometer (NIMS). A Geological Survey team was instrumental in the conception, development, production, and testing of this new instrument. These scientists also will participate in analyzing the images or maps of Jupiter and its satellites that will be produced by the instrument. NIMS will provide a wide range of new diagnostic compositional and thermal data that will help answer more of Io's mysteries.

Microbiology—A New Approach in Mineral Exploration

U.S. Geological Survey researchers are investigating the use of a simple microbiological test as an aid in mineral exploration. Preliminary studies have shown that the dormant spores of a common species of soil bacteria, *Bacillus cereus*, are present in elevated numbers in soils over several types of mineral deposits, including vein-type and disseminated gold deposits, tested so far.

During the last decade, environmental studies indicated that different heavy metals somehow create a selective pressure for various antibiotic resistances in bacteria living in metal-polluted sediments. In other words, bacteria resistant to metals and antibiotics may be indicative of metal-containing environments. However, studies of bacterial antibiotic resistance had never been conducted in naturally metalliferous soils associated with ore deposits.

When Geological Survey researchers tested the penicillin resistance of a normally penicillin-sensitive group of bacteria (the aerobic, spore-forming genus *Bacillus*) in soils near a porphyry copper deposit, they found a much larger percentage of the bacteria of this genus resistant to penicillin in the metal-rich soils directly over the deposit than in more normal soils adjacent to the deposit (fig. 1). Significant correlations were found between the detailed distribution pattern of many different heavy metals in these soils and the pattern of penicillin resistance in *Bacillus* species.

Further investigation showed that the numbers of one particular organism, *Bacillus cereus*, the most penicillin-resistant member of the genus, statistically explained the penicillin-resistance data. In fact, the distribution of this species correlated better with the distribution of heavy metals than did the penicillin-resistance pattern. The more laborious penicillin-resistance test, therefore, was dropped and replaced by a rapid assay method for *Bacillus cereus*. Tests now underway are providing some clues as to why this species colonizes soils over certain ore deposits.

In soils at a current "test" deposit, a weathering, 50-million-year-old copper deposit, the most representative type of microfungus is a *Penicillium* mold that produces penicillin and other antibiotics. This variety of mold has long been recognized as a problem in metal-electroplating vats and in laboratory jars of Fehling's solution (17 percent copper sulfate). These molds, which are among the most metal-tolerant organisms on Earth, may owe this special trait in part to the extraordinary metal-binding properties of penicillamine, a principal breakdown product of penicil-

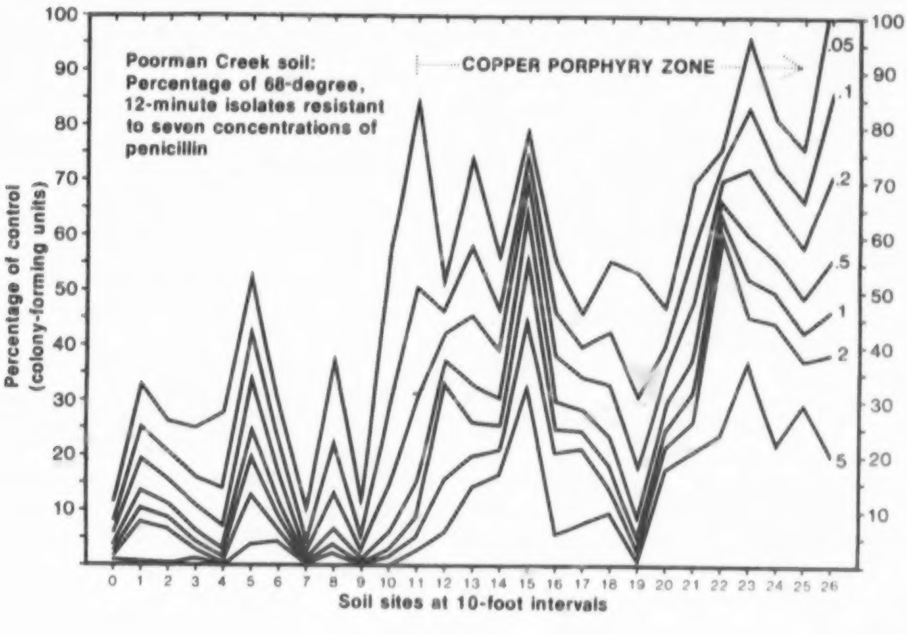


Figure 1. *Percent of* Bacillus *species (pastuerized isolates) resistant to the seven lowest test concentrations of penicillin. A significant increase in percent penicillin-resistant* Bacillus *species coincides with the barren metalliferous soil over the porphyry copper deposit.*

lin. Other fungal antibiotics, such as kojic acid, also form strong complexes with heavy metals. The ore deposit apparently provides conditions in which microorganisms that produce strong metal-binding agents, such as penicillin, have an advantage over other microorganisms.

Pure strains of *Bacillus cereus* were isolated from soils over and adjacent to the test deposit. These pure strains then were tested for their resistance to 32 different antibiotics and the salts of 21 metals. A pattern of elevated multiple-antibiotic resistance in these isolates coincided well with the area over the ore deposit. Surprisingly, the metal-resistance pattern showed a much poorer correlation with the deposit than the antibiotic-resistance pattern. Apparently, multiple antibiotic resistance is a far more important survival characteristic for *Bacillus cereus* in polymetallic soils than is metal resistance. In addition, the isolates from the deposit area were significantly more resistant to penicillin than isolates from adjacent areas, a finding which strongly suggests that penicillin is an important selective agent for bacteria over the deposit at the genus and the species levels.

These different findings correlated very strongly with results of other experiments that showed that highly penicillin resistant *Bacillus cereus* isolates from the deposit area could grow in ultrapure water with no other nutrient than bits of colonies of the representative penicillin-producing mold. Penicillin resistance is apparently a kind of "meal ticket" for this bacterium. Thus, *Bacillus cereus* is better suited than other *Bacillus* species to obtain nutrients in a polymetallic soil.

After finding that *Bacillus cereus* populations are concentrated over vein-type gold deposits, Geological Survey scientists are trying to learn if distributions of the spores can help locate the current number-one mineral target—large-tonnage, disseminated gold deposits. Encouraged by these recent results, these scientists have begun investigations to determine the details of the ecology and the indicator potential of this organism in soils overlying a wide variety of economic mineral deposit types.

Research on the Quality of the Nation's Coal

In 1973, the oil embargo emphasized to the United States its economic vulnerability to supplies of foreign energy resources. As a result, the Nation has begun to use more of its abundant coal resources. This substitution has not been without cost. The environmental impact of acid precipitation and toxic metals, the pollution of ground water by scrubber sludge, reduced boiler efficiency, and excess slagging problems caused by the use of a fuel other than the one for which systems were designed are but a few of the penalties to be paid for fuel switching. The discussions surrounding acid precipitation and other environmental impacts, substitution of western coal for eastern coal, boiler efficiency, and improved export markets are national and international concerns. In these discussions, the use of scientific knowledge and skills to mitigate or improve the situation must be addressed. Coal quality is the common denominator in all of these problems and, thus, is the principal avenue of research that will lead to their solution.

The Clean Air Act, enacted in 1970, was intended to lower commercial boiler sulfur emissions into the atmosphere to no more than 1.2 pounds of sulfur dioxide per million British thermal units from any powerplant built or modified after August 17, 1971. Coal capable of meeting these requirements without flue-gas scrubbers has become known as compliance coal. Recent proposals to lower the compliance coal requirement to 0.6 pound sulfur dioxide per million British thermal units do not address properly the availability of coal that can meet this standard or the economic impact it will have on the U.S. coal industry. The considerations in the compliance coal discussions are How much sulfur is there in U.S. coal? How much will meet various emission standards? What is its variability? Can sulfur and other contaminants be cleaned from coal? Can high-sulfur coal be blended with lower sulfur coal to meet various standards? Most available data are based on coal that has been or is being mined and not on coal to be mined. Thus, answers to these questions are difficult to obtain because little reliable data on the sulfur content of unmined U.S. coal are available. However, decisions and regulations based on these inadequate data continue to be made.

The conversion of powerplants from eastern to western coal or from oil to coal is technically difficult. Most powerplants generally are built for a particular "design fuel." The plant boiler and attendant combustion processes are engineered around the physical and chemical properties of the "design fuel." Thus, such properties as British thermal units, sulfur and ash contents, volatile matter, and the content of many of the inorganic elements in the coal are critical elements in the plant design. Switching from a higher to lower British-thermal-unit coal, which contains less sulfur, may appear, on the surface, to be an ideal solution to meeting the standards required by the Clean Air Act; however, other coal-quality characteristics for which the plant was not designed may cause problems. The amounts of such elements as silicon, aluminum, iron, sodium, potassium, magnesium, and calcium and of such minerals as quartz, clays, and sulfides in the coal will determine some of the chemical reactions in the combustion chamber. Some coal-quality problems which are critical to the environment are not confined to the combustion chamber but are more widely distributed. Volatile minor and trace elements such as mercury, selenium, and arsenic are emitted through the stack into the air either as gases or absorbed on particulates. Many of these elements also may be concentrated in the bottom ash or in the scrubber sludge and, upon disposal, can be released into the environment by weathering, leaching, and oxidation processes.

The Federal Government owns approximately 70 percent of the coal west of the Mississippi River, and many tracts of Federal coal have been leased for mining by the Department of the Interior. In the 1950's and 1960's, only the heat content and ash values were deemed important coal-quality properties; more recently, toxic trace elements and sulfur contents of the coal, major and minor constituents of the ash, and ash-fusion temperatures and coking properties have become critical to the marketability and royalties paid for Federal coal. In recent years, coal quality also has become a critical component of the U.S. coal export market. Foreign buyers and investors are requiring coal-quality certification. Their quality requirements are focused on the content of sulfur, ash, phosphorus, fluorine, chlorine, mercury, arsenic, silicon, aluminum, calcium, potassium, sodium, and other elements.

Reliable data on the chemical constituents have now become essential to making wise economic, technologic, and environmental decisions. Such data can be provided only by characterizing the quality of our Nation's coal and by developing predictive quality models in advance of leasing, development, and use of coal. The U.S. Geological Survey conducts research in the following coal-quality topics to address these requirements:

COAL GEOCHEMISTRY

During the last 50 years, tens of thousands of U.S. coal samples have been analyzed. However, many of these analyses are useless because sample locations were known inadequately or correlated inadequately, samples were not collected or prepared properly, or samples were not analyzed according to standard methods. In addition, many analyses are part of the confidential records of coal companies and, thus, are not available to the public. To correct these inadequacies, the Geological Survey organized a cooperative collecting and testing program with the geological surveys of the States with coal deposits. This effort has resulted in the collection and the analysis of more than 8,000 carefully documented coal samples (fig. 1). This coal-quality data base contains data for ultimate and proximate analyses, coking properties, heat content, forms of sulfur, ash-fusion temperatures, and more than 50 inorganic elements for each sample. This data base is available and used by

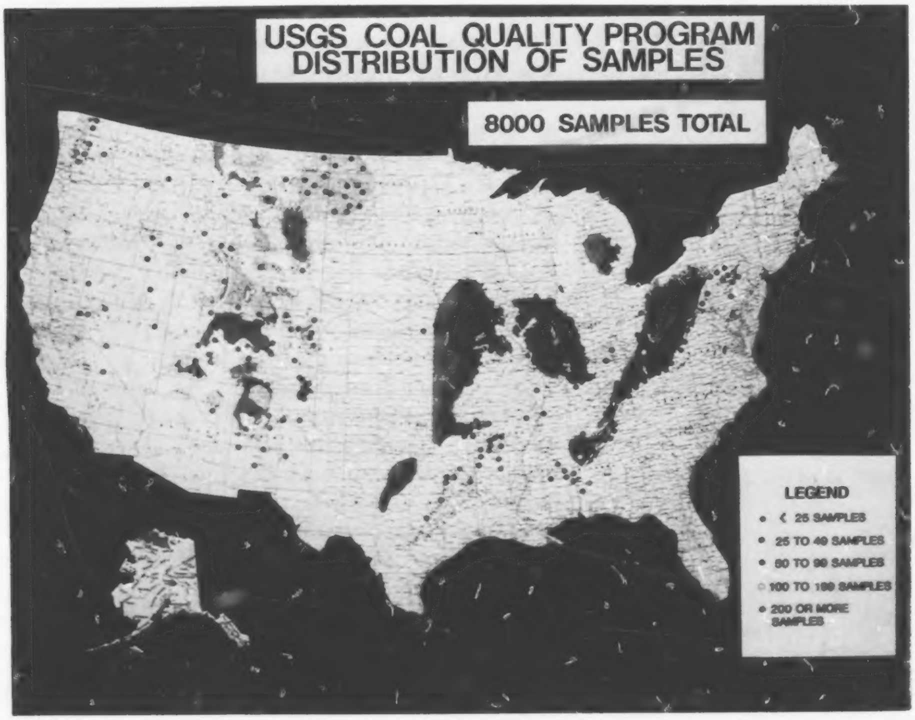


Figure 1. *Distribution of coal samples collected from U.S. coal basins.*

many Federal and State agencies, academic groups, and a variety of industry and consultant groups. It is the most complete, publicly available coal-quality data base in the world, and more data are being added daily to provide detailed regional and basinal coal-quality assessments.

COAL MINERALOGY

The mineralogy of U.S. coal is being studied to identify and quantify the minerals and the mode of occurrence of minor and trace elements in the coal. These investigations provide data useful in the design of coal-cleaning and coal-preparation facilities and contribute to understanding and predicting the behavior of various minerals in combustion chambers.

COAL PETROLOGY

Coal petrology studies focus on the identity, concentration, and distribution of inorganic and organic matter. Their physical characteristics and the degree of coalification of the organic matter (rank) determine the properties, reactivity, and yield of coal. Changes in coal rank, depth of burial, and depositional environment currently are being studied, and techniques are being developed to describe systematically, interpret, and predict the occurrence and distribution of high-quality coal.

PREDICTIVE COAL-QUALITY MODELS

An important objective of national coal-quality studies is the integration of basinwide geologic, stratigraphic, and sedimentologic data with coal geochemistry, mineralogy, and petrology data to develop and test predictive models. These models, based in part on investigations of modern peat deposits, will lead to a better understanding of the origin of high-quality coal and of the coalification processes.

Current Geological Survey research on coal quality is focused on the Appalachian region of the Eastern United States and on the Powder River, San Juan, Big Horn, Green River, south central Utah, and eastern Unita regions of the Western United States. These studies require the integration of geochemical, sedimentologic, tectonic, and paleoecologic data with geologic framework data on regional and local scales. Through the activities described above, the coal resources best suited to various end uses will be identified and quantified, and predictive models will be made available to support resource information, regulation, and land policy decisions.

The World Energy Resources Program

PROGRAM GOALS

The rhetoric of "energy independence" which emerged from the shocks of the 1973 oil embargo gradually has been replaced by an understanding of the complex web of interdependence among the world's nations with respect to petroleum and other energy resources. Consequently, reliable information from throughout the world about reserves and the probable location and extent of undiscovered oil, gas, coal, and uranium are indispensable components in planning for the Nation's energy security. Such understanding allows us to distinguish the anomalous and temporary fluctuations in world oil supply and demand from historically and geologically derived trends.

A geological understanding of the characteristics of petroleum occurrence also offers a base for planning national strategies for transition to other forms of energy. Development of alternate energy sources requires long lead times which cannot be supported by market-determined forces that limit the focus of attention to immediate economic viability.

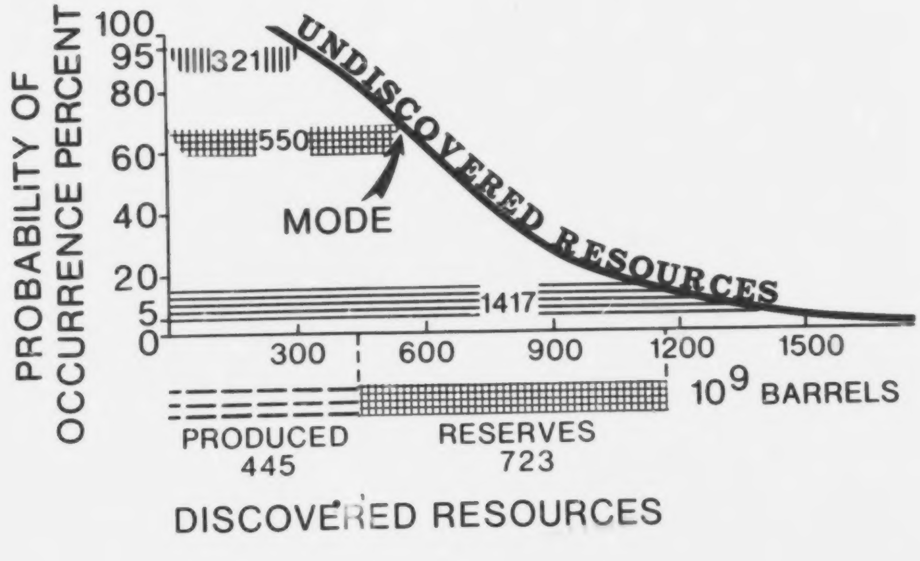
Because of the crucial role of world energy-resource assessments in decisionmaking about long-term national energy strategies and the always controversial nature of such assessments, the U.S. Geological Survey program concentrates on developing a reliable data base that will enable multidirectional analyses of the assessments as exploration proceeds.

MAJOR ACHIEVEMENTS

The major achievement of the World Energy Resources Program this fiscal year has been the completion of a report on the distribution and quantitative assessment of world crude oil reserves and resources, which was presented at the 11th World Petroleum Congress in London. Important insights from this comprehensive report include the following:

- Estimates of undiscovered resources, although large, are, nonetheless, sharply reduced relative to some earlier assessments because no new, major prospective exploration areas have been found (fig. 1).
- The geographic distribution of world oil is and will remain narrow and highly concentrated with respect to producing capacity. The Middle East will become ever more dominant in world energy supply (fig. 2).
- World production of crude oil over the past decade has exceeded discoveries

Figure 1. *Ultimate resources of crude oil.*



by some 70 billion to 80 billion barrels of oil. The deficit derives from reduced efficiency in the discovery process not less exploration (fig. 3).

These insights suggest that the current widespread perception that all is well with the world oil supply is unsupported by data. Petroleum discoveries are decreasing as projected demand due to economic recovery is rising. The current optimistic concept of adequate supply derives from a market perspective focused only on the marginal excess producing capacity.

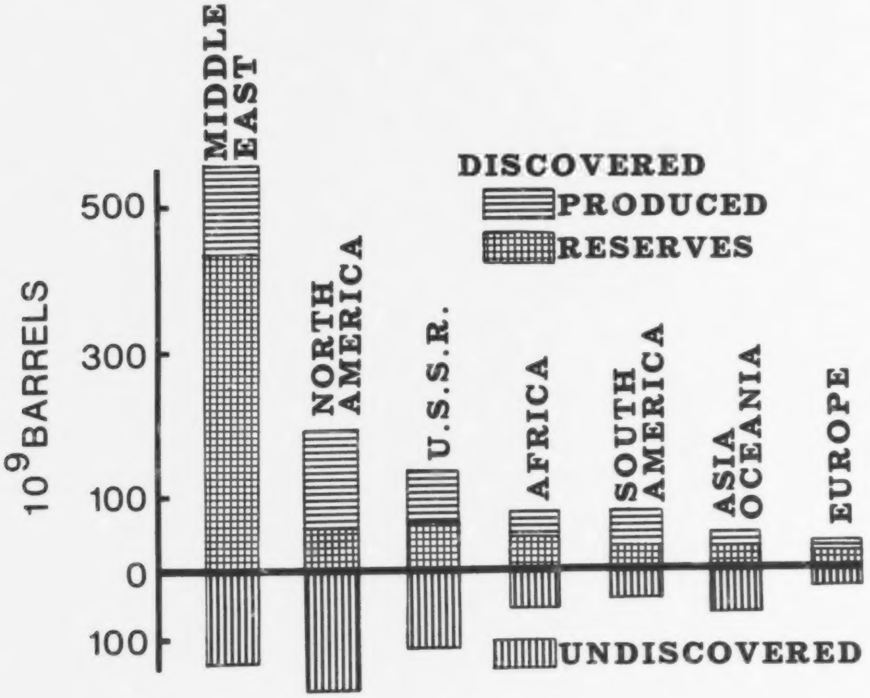


Figure 2. *Regional distribution of world crude oil.*

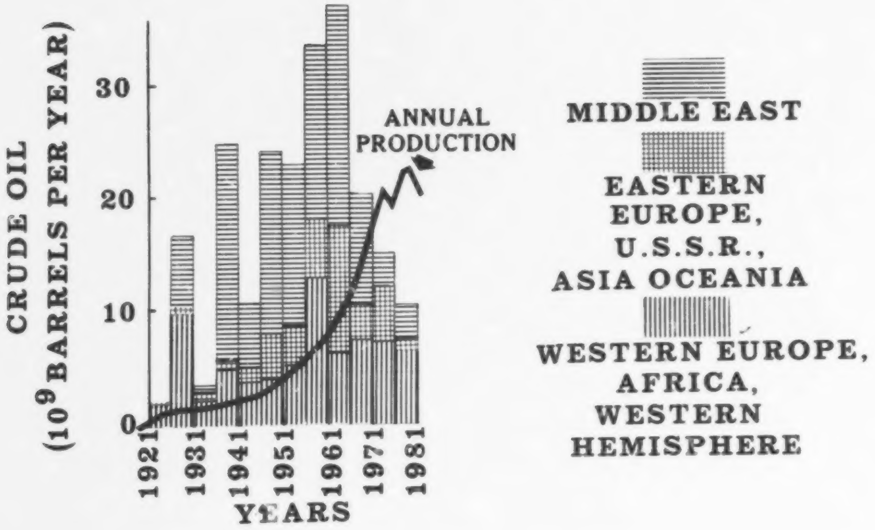


Figure 3. *World crude oil discovery rate averaged over 5-year periods.*

The margin of excess producing capacity outside the Persian Gulf (about 3 million–4 million barrels of oil per day) is minimal and could disappear with any changes in consumption (currently about 55 million barrels per day) derived from economic recovery or sudden disruption of supply (7 million–8 million barrels of oil per day are shipped through the Straits of Hormuz). Preliminary investigations on the distribution and availability of natural gas indicate that the picture for world gas resources is strikingly similar to that for world oil resources in terms of British thermal unit equivalent quantities and their distribution. An inescapable conclusion is that the world remains vulnerable to a renewed and sudden energy crisis in terms of availability and deliverability.

FUTURE INVESTIGATIONS

The World Energy Resources Program will be suspended in fiscal year 1985. However, the Geological Survey will retain the capability to provide expert advice regarding foreign resources that potentially have a bearing on the U.S. domestic resource base. Specific assessment work related to the mission responsibilities of other Federal agencies will be performed on a reimbursable basis.

CONCLUSION

In decades past, stable price and supply of petroleum limited our concern to the most obvious geological questions—Where were the fields likely to be found? and How good were they? Today, unpredictable prices, political upheavals in the world's major oil-producing region, changing economic supply-and-demand relations and doubts about the long-term availability of natural resources require that our analyses encompass a more complex and varied range of questions. The Geological Survey attempts to meet the needs of changing times by broadening our base of knowledge about the distribution and potential future availability of energy minerals throughout the world. Because so much of a nation's economic and social welfare is related to a dependable and realistically priced energy supply, the answers to these questions hold the key to a secure and stable future.

The Antarctic Leg of "Operation Deep Sweep"

During January and February 1984 (figs. 1, 2), marine geologists aboard the Research Vessel *Samuel P. Lee* conducted two surveys along the Antarctic continental margin south of Australia and New Zealand. The purpose of the surveys was to define the geologic structure and the sedimentary basins of the region. The surveys included geophysical profiling and seafloor sampling to determine the ages and physical and geochemical properties of the rocks. The Antarctic portion of "Operation Deep Sweep" (a year-long, pole-to-pole series of surveys to investigate seabed oil and gas and mineral deposits) was conducted as part of the U.S. Antarctic Research Program in cooperation with the National Science Foundation, the U.S. Coast Guard, and the U.S. Navy. In addition to U.S. Geological Survey personnel, scientists from U.S. universities and from Australia and New Zealand contributed to the success of the voyage.

A newly published Geological Survey circular describes the types of data collected and provides a brief discussion of preliminary results based on shipboard analyses of seismic and other geophysical data. The report, *Marine Geological and Geophysical Investigations of the Antarctic Continental Margin, 1984*, and scientific data collected on the Antarctic voyage will be made available for exchange under the terms of the Antarctic Treaty.

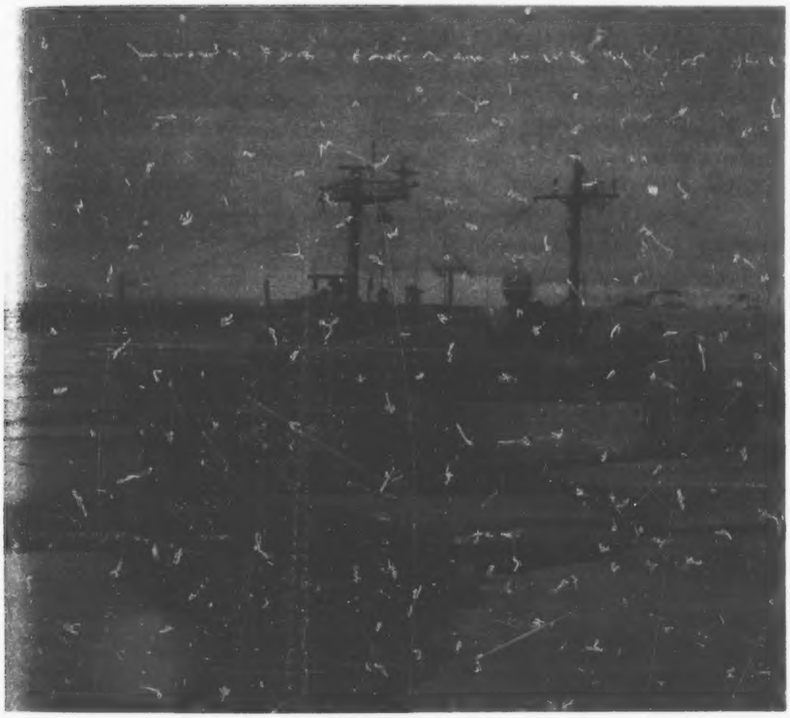


Figure 1. *The U.S. Geological Survey's Research Vessel* Samuel P. Lee *exchanging scientific personnel and reprovisioning in McMurdo Sound, Antarctica.*

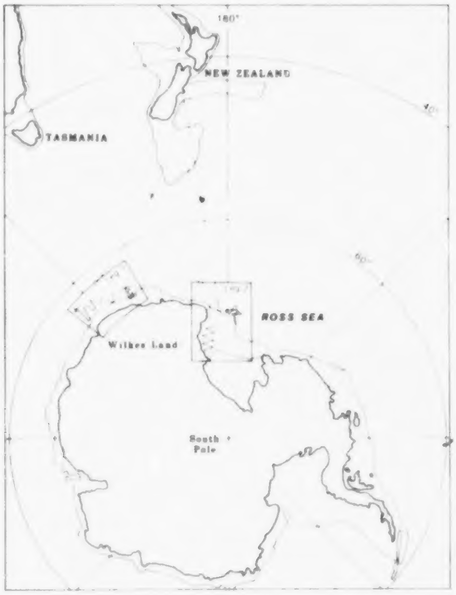


Figure 2. *Map showing the regions where the two surveys were carried out by the U.S. Geological Survey's Research Vessel* Samuel P. Lee *during January and February 1984 in the waters and continental margins surrounding Antarctica.*

Water Resources Investigations

Mission and Organization

The U.S. Geological Survey has the major responsibility within the Federal Government for assessing the Nation's water resources. It collects basic data and conducts special investigations to provide essential information for planners and managers. Increasing demands for water from a wide variety of users require that planners at Federal, State, and local levels establish new priorities for use. Sound judgment in determining such priorities depends on access to accurate hydrologic information and impartial expertise.

OFFICE OF WATER DATA COORDINATION

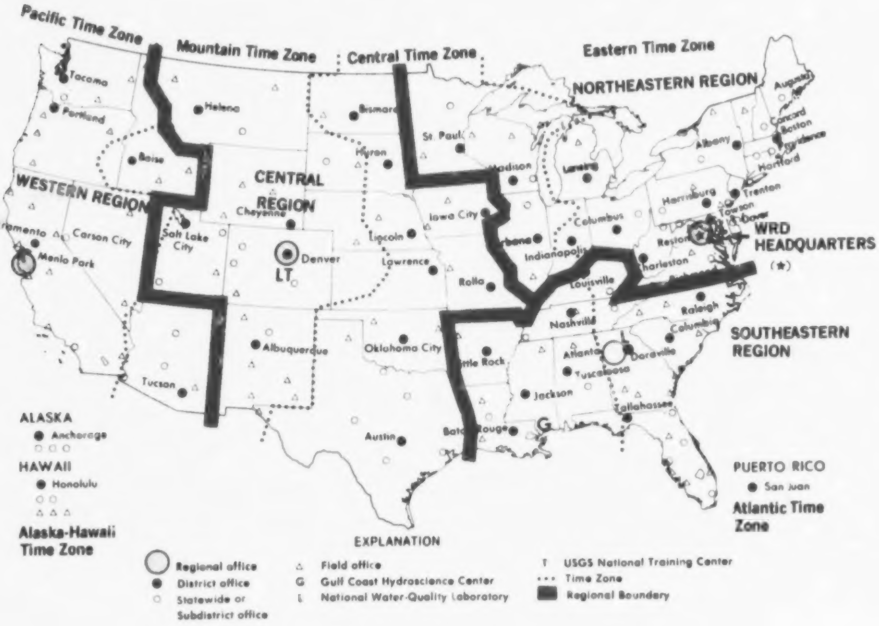
A major new responsibility was assigned to the Survey in 1964 when it was designated the lead agency for coordinating water-data acquisition activities of all Federal agencies. Activities include those that produce information on streams, lakes, reservoirs, estuaries, and ground water. This coordination effort minimizes duplication of data collection among Federal agencies and strengthens the data base and its accessibility.

PROGRAMS

Water Resources Division programs fall into four categories: the Federal Program, the Federal-State Cooperative Program, Assistance to Other Federal Agencies, and the Non-Federal Reimbursable Program.

THE FEDERAL PROGRAM

The data collection, resource investigation, and research activities of this program are carried out in areas where the Federal interest is paramount. These include bodies of water in the public domain, river basins and aquifers that cross State boundaries, and other areas of international or interstate concern. Activities include operation of surface- and ground-water quantity and quality measurement stations throughout the country, the Divison's Central Laboratories System, hydrologic research and analytical studies, and a variety of supporting services.


Pacific Time Zone
Mountain Time Zone
Central Time Zone
Eastern Time Zone
NORTHEASTERN REGION
CENTRAL REGION
WESTERN REGION
SOUTHEASTERN REGION
WRD HEADQUARTERS
(★)
Tacoma
Portland
Boise
Helena
Bismarck
Huron
St. Paul
Madison
Lansing
Albany
Augusta
Concord
Boston
Providence
Hartford
Trenton
Harrisburg
Towson
Dover
Reston
Columbus
Charleston
Iowa City
Urbana
Indianapolis
Louisville
Lincoln
Lawrence
Rolla
Cheyenne
Salt Lake City
Denver
LT
Sacramento
Carson City
Menlo Park
Tucson
Albuquerque
Oklahoma City
Little Rock
Nashville
Raleigh
Columbia
Atlanta
Doraville
Tuscaloosa
Jackson
Tallahassee
Baton Rouge
G
Austin
ALASKA
Anchorage
HAWAII
Honolulu
Alaska-Hawaii Time Zone
PUERTO RICO
San Juan
Atlantic Time Zone
EXPLANATION
Regional office
District office
Statewide or Subdistrict office
Field office
G Gulf Coast Hydroscience Center
L National Water-Quality Laboratory
T USGS National Training Center
Time Zone
Regional Boundary

Location of principal offices of the U.S. Geological Survey's Water Resources Division in the conterminous United States. Cities named are those where Regional and District Offices are located. Puerto Rico is included in the Southeastern Region, and Alaska and Hawaii are included in the Western Region.

THE FEDERAL-STATE COOPERATIVE PROGRAM

The Cooperative Program is based on the concept that Federal, State, and local governments have a mutual interest in evaluating, planning, developing, and managing the Nation's water resources. The immense size of the task of appraising the Nation's water resources precludes accomplishment by Federal efforts only. Similarly, State and local agencies working independently cannot relate to the sizable regional aspects of hydrologic systems. Because many water problems begin at the local level, the Geological Survey has cooperative agreements with all States under which each party funds one-half of the cost of financing studies of water resources. Cooperation through this program provides an economical and comprehensive system for water-resources assessments.

Most projects under the Cooperative Program respond to a recognized problem or define a potential one. In addition to data collection, programs may focus on water use and availability, the impact of man's activities on the hydrologic environment, and energy-related water demands that may strain available water supplies. In emergency situations, such as drought or flood, events are extensively monitored, and the data accumulated under the Cooperative Program prove invaluable.

ASSISTANCE TO OTHER FEDERAL AGENCIES

With funds transferred from other Federal agencies, the Geological Survey performs a wide variety of work related to the specific needs of each agency.

NON-FEDERAL REIMBURSABLE PROGRAM

Non-Federal reimbursable funds are unmatched funds received by the Geological Survey from State and local agencies in situations where Federal and State agencies are interested in investigation of water resources but where matching Federal funds are either unavailable or are not otherwise applicable to cost sharing.

Budget and Personnel

At the end of fiscal year 1984, the Water Resources Division employed 3,367 full-time personnel. This number included scientists and engineers, who represented all fields of hydrology and related sciences, technical specialists, and administrative, secretarial, and clerical employees. An additional 634 permanent part-time and intermittent employees assisted in the work of the Division.

The $218.5 million obligated in 1984 for water resources investigation activities came from the following sources:

1. Direct Congressional appropriations.
2. Congressional, State, and local appropriations for 50–50 funding in the Federal-State Cooperative Program.
3. Funds transferred from other Federal agencies.
4. Funds transferred from State and local agencies.

Highlights

In the following sections, highlights from some of the major programs are described.

New Merit Proposal Process Sparks the Federal-State Cooperative Program

The Federal-State Cooperative Program continues to be the largest component of the U.S. Geological Survey's water-resources activity. This Program was carried out in working partnership with more than 800 State, regional, and local agencies during fiscal year 1984. Joint funding in the 50–50 matching Cooperative Program totaled about $100 million and comprised almost one-half of the overall program of the Water Resources Division. Hydrologic data collection and interpretive investigations were being conducted in every State, Puerto Rico, and several United States territories.

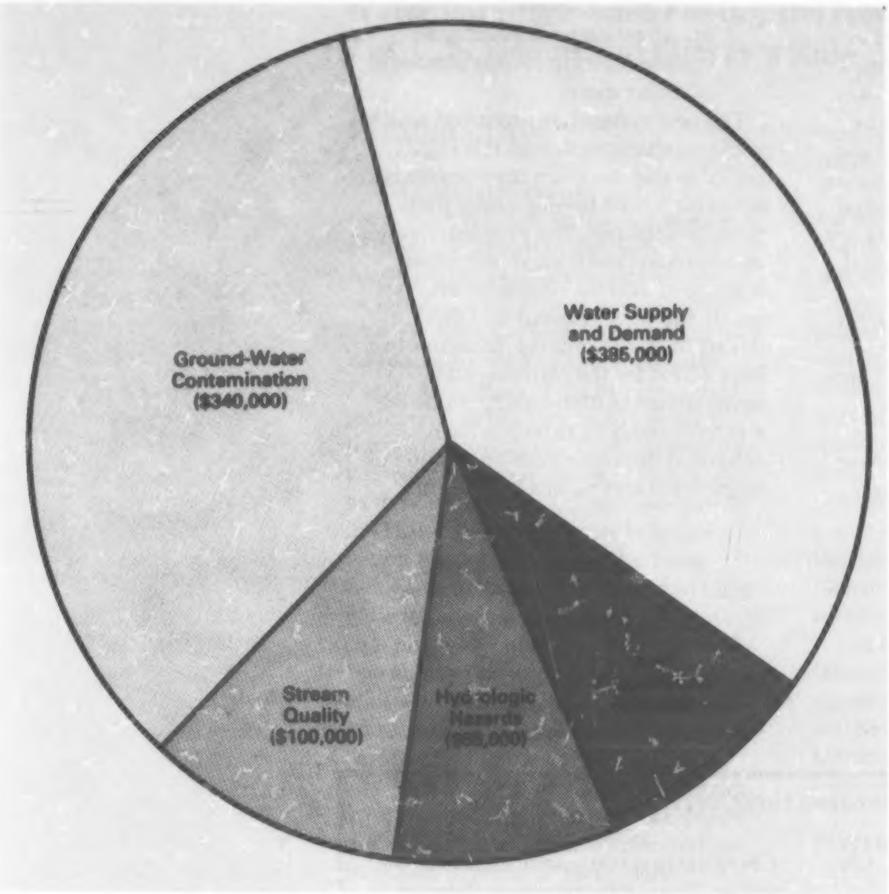
Each year, cooperator proposals typically exceed Federal funds that are available for matching by several million dollars. Priorities for data collection and hydrologic investigations are based on a continuing, detailed analysis of water problems and issues. This analysis is carried out through discussions with State and local cooperators, Federal agency officials, and the general public. For 1984, the principal concerns identified in these discussions were ground-water contamination, water supply and demand, stream quality, hydrologic hazards, and acid precipitation. Most of the Federal matching funds are allocated to highest priority activities by the Division's four Regional Offices after ranking the work proposed in their respective geographical areas of responsibility.

The Geological Survey now has a new process for funding selected proposals for water-resources investigations as part of the Federal-State Cooperative Program. In brief, part of the Cooperative Program appropriation is identified to undertake investigations chosen from a number of proposals on the basis of a merit ranking system. The process provides for a national level evaluation of each proposal based on the potential for transferring knowledge to be gained to other locations, the originality and quality of the scientific approach, and the anticipated contribution of the investigation to the advancement of science and technology. The Federal support for merit proposals was $1 million in fiscal year 1983 and a like amount in fiscal year 1984; with matching cooperative funds, the total was about $2 million each year. In 1983, 16 investigations were selected of the 33 proposed, and, in 1984, 15 of 44 proposals were selected. Plans are to identify $1 million of U.S. Geological Survey matching funds for investigations to be chosen through this process in fiscal year 1985.

The new process formalizes existing procedures that have been used for the past 10 to 15 years to rank candidate proposals for the allocation of funds. Additional effort is applied, however, to ensure that the highest priority work is undertaken and that the anticipated technical contributions to the science of hydrology will be of top quality. Each merit proposal is reviewed and evaluated separately by five members of the Geological Survey's senior staff. The group then consolidates rankings, arbitrates differences, and allocates funds to the investigations in priority order.

Examples of current investigations selected through the merit proposal process are as follows:

- *Hazardous waste, Washington State.*—In the State of Washington, more than 200 hazardous waste sites are located where a high probability of leachate impacts surface and ground water. The State is developing a major program to deal with this problem and has asked the Geological Survey for technical assistance. The resulting investigation consists of the following phases: (1) hydrogeologic characterization of existing hazardous waste sites, (2) research on how the pollutants are moving through the hydrologic system and on the reaction processes that are involved, (3) broad characterization of the most and least suitable areas within the State for land disposal of hazardous waste, and (4) technical assistance in the evaluation of the hydrogeological aspects of pro-



As part of the Cooperative Program, the merit proposal process in fiscal year 1984 focused $1 million of Federal matching funds on high-priority water-resources issues.

posals and reports being considered by the State.

- *Ground water in fractured-limestone formations near Brunswick, Georgia.*—The dependence upon fractured-rock aquifers to supply much of the Nation's ground water makes it imperative that methods continue to be developed to simulate accurately ground-water movement in these aquifers. The primary objectives of this investigation are to evaluate the strengths and weaknesses of existing mathematical models for simulating hydrogeologic flow in a fractured-limestone aquifer and to develop, if necessary, a mathematical model capable of simulating flow in a fractured-rock aquifer. Results from this study will contribute to the understanding of the fractured and locally faulted limestone aquifer in the Brunswick area and will have transfer value to investigations of fractured-rock aquifers elsewhere.

- *Wastes associated with mining, North Dakota.*—Low grade uranium ore in western North Dakota's lignite was concentrated by open-pit burning of the lignite during the 1950's and 1960's. Investigations since October 1983 reveal that base flows in streams as far as 4 miles downgradient from the open pit have a uranium content in excess of 200 micrograms per liter, about 10 times the regional background. (Nuclear Regulatory Commission regulations allow a maximum permissible concentration of 30,000 picocuries of natural uranium per liter for release into water.)

- *Precipitation quality, Massachusetts.*—An investigation of the relationships between air-mass movement and variations in the quality of precipitation has been underway in Massachusetts since September 1983. Values of pH in precipitation samples range from 3.7 to 5.4; most are from 4.2 to 4.8. The value 5.6 is considered to be the dividing line between acid and nonacid precipitation. Precipitation with a pH of less than 5.6 is called "acid rain." Meterological data are being obtained from the National Weather Service and private sources to identify such characteristics as air-mass source, trajectory, storm type, and season. These investigations are designed to clarify some of the questions regarding acid precipitation in the Northeastern United States, and the methods developed in this investigation have significant transfer value to similar studies in other locations.

The new system has produced worthwhile results even though it is highly probable that the merit investigations could have been funded under traditional procedures. The program development process has been strengthened because of the more intensive analysis within the Water Resources Division during the merit ranking. Incentive has been added for the planning and development of high-quality proposals, and technology transfer has been enhanced through closer interaction of operational and research programs.

WATER RESOURCES SCIENTIFIC INFORMATION CENTER

Authorized by the Water Resources Research Act of 1964, the Water Resources Scientific Information Center was established in 1967 as a national center to increase the availability and awareness of water-related scientific and technical information. In accomplishing this goal, the Center abstracts water-resource publications and makes the information available to the water-resources community and the public through publications and computerized bibliographic information services. The Center formerly was located in the Office of Water Research and Technology, but, in late 1982, the Secretary of the Interior transferred it to the U.S. Geological Survey's Water Resources Division where it would complement the Division's long-standing program of disseminating water information to the public. The Center produces *Selected Water Resources Abstracts*, a monthly abstracting and indexing journal now in its 17th volume, which covered about 6,000 abstracts in 1984, with projections of 8,000 in 1985. The computerized abstracts file contains about 170,000 abstracts that have appeared in *Selected Water Resources Abstracts* since 1968. This file can be searched by Federal agencies and their contractors by means of the U.S. Department of Energy's RECON system and is commercially searchable worldwide via DIALOG Information Services, Inc. Topical bibliographies are produced along with the abstracts file such as the *Abstracting and Indexing Guide* and the *Water Resources Thesaurus.*

Water-Quality Issues Facing the Nation—The U.S. Geological Survey's Role

INTRODUCTION

The continued growth and vitality of the Nation is linked to the maintenance of or improvement in the quality of its water resources. Water quality is the physical, chemical, and biological characteristics of water with regard to its suitability for a specified purpose. Public awareness of the importance of water quality has increased greatly in the past two decades. The Congress has passed such major pieces of legislation as the Clean Water Act, the Safe Drinking Water Act, the Resource Conservation Recovery Act, and the Toxic Substances Control Act. State and local governments and industry have made significant commitments to water-pollution abatement. Through these combined efforts, the quality of the Nation's rivers and streams has improved significantly compared with the quality of 15 years ago. This is true even though industrial activity and population have increased during this period with corresponding increases in water use and in the volume of wastes discharged. For example, 15 years ago, low dissolved-oxygen levels were common in rivers and streams because of the discharge of large volumes of oxygen-demanding wastes. Today, as a result of the construction of new waste-treatment plants and the upgrading of existing plants, this is no longer true. Despite progress, several water-quality issues still remain. Among them are the contamination of surface and ground water from nonpoint-source pollution, acid precipitation, and the disposal of hazardous wastes.

The U.S. Geological Survey's role in water-resources management is to provide hydrologic data and understanding of hydrologic processes affecting the Nation's water resources. The Geological Survey monitors the quality of surface and ground water, conducts research to increase understanding of the processes that affect the quality of water, and conducts applied interpretive studies to determine the causes of specific observed changes in water quality and to predict the nature of future changes that are likely to occur due to changes in land use or uses of surface- and ground-water resources. The three components—monitoring, research, and applied interpretative studies—are highly interactive. For example, theories arising from research and interpretative studies provide the foundation for designing monitoring networks and for detecting water-quality trends. Further, today's research results may provide increased understanding or new techniques for next year's interpretive studies, and monitoring may uncover problems that require interpretive investigation or additional research.

The following examples of research, interpretive investigations, and monitoring describe some of the Geological Survey's efforts to provide the information needed for addressing the water-quality issues facing the Nation.

POTOMAC RIVER ESTUARY STUDY

The Potomac River Estuary Study, which began in October 1977, was one of seven Geological Survey river-quality assessments and the only one to concentrate on estuarine problems. As part of the Potomac River Estuary Study, the sources and fate of sediments and several major nutrients were examined. This information is important not only for developing water-quality management strategies for the Potomac River estuary, it is essential for developing management strategies to protect the Chesapeake Bay.

Estuaries are potentially the most productive as well as the most fragile and endangered areas of our Nation's coastal environment. Because they are the meeting place of saltwater and freshwater, estuaries are complex hydrodynamic, chemical, and biological environments. Sediments accumulate in estuaries along with the attached nutrients, metals, and trace organic compounds. The attached substances may become stored permanently or temporarily in the bottom sediments thereby contributing to eutrophication and, in the case of metals and organics, sometimes accumulating in aquatic life forms.

From 1979 to 1981, water-quality data were collected twice weekly at six stations along the 116-mile tidal reach between Chain Bridge near Washington, D.C., and the Chesapeake Bay (fig. 1). Monthly amounts of sediment and nutrients passing the stations were estimated by a computer model and used, together with data from sewage-treatment plants, tributaries, and nonpoint sources, to determine sediment and nutrient budgets for the major segments of the tidal river and estuary (J. P. Bennett, written communication, 1984).

All of the suspended sediment contributed to the Potomac River estuary came from nonpoint sources. Of the total annual amount of suspended sediment; 56 percent came from sources upstream from Chain Bridge, 43 percent came from sources downstream from Chain Bridge, and 1 percent came from upstream-flowing saline water entering from the Chesapeake Bay. All of the suspended sediment was trapped in the estuary.

Nonpoint sources downstream from Chain Bridge contributed 17 percent of the nitrogen and 32 percent of the phosphorus. Sources upstream from Chain Bridge contributed 58 percent of the nitrogen and 43 percent of the phosphorus. The relative amounts of nitrogen and phosphorus contributed by point and nonpoint sources upstream from Chain Bridge are unknown. The balance of the nutrient loads, 25 percent nitrogen and 25 percent phosphorus, was contributed by point sources.

Seventy-five percent of the nitrogen and phosphorus contributed to the Potomac was trapped in the estuary during the study period. Whether these materials are stored permanently in the estuary or will later be transported to the Chesapeake Bay under extreme hydrologic conditions, such as hurricanes, is unknown.

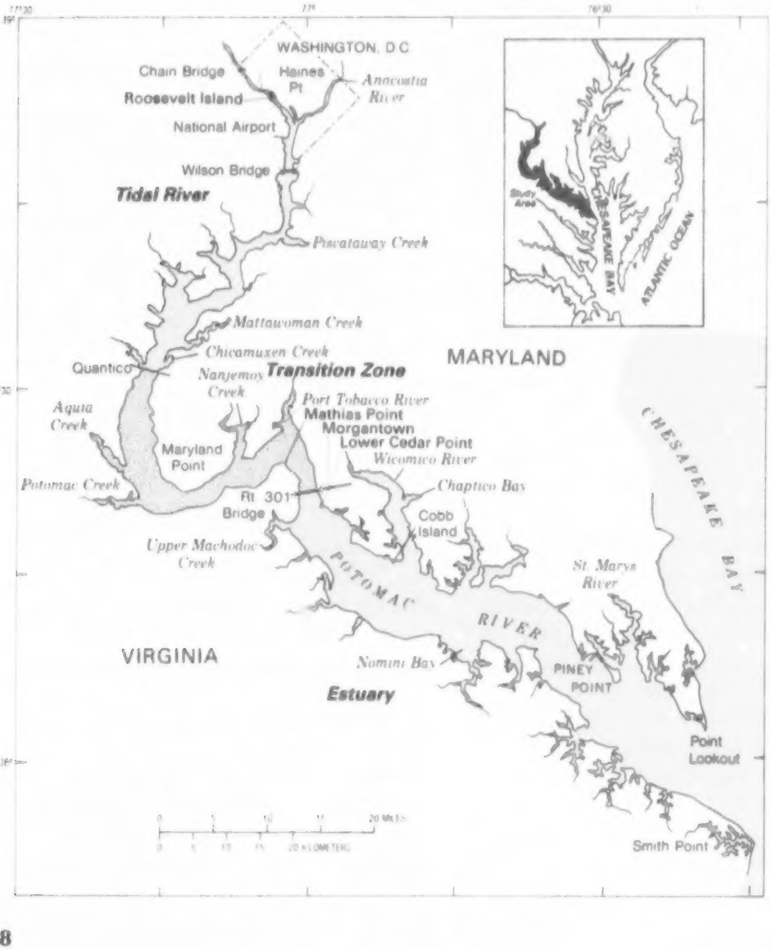
NATIONAL MONITORING NETWORKS USED TO ASSESS TRENDS IN RIVER QUALITY

Two nationwide water-quality monitoring networks (fig. 2), the National Hydrologic Bench-Mark Network and the National Stream Quality Accounting Network (NASQAN), are operated by the U.S. Geological Survey.

The Bench-Mark Network, which was begun in the mid 1960's and consists of collection sites in 52 basins, is designed to characterize the hydrology and water quality of small basins that are in a near-natural state. Study of streams draining these basins helps to explain how much of the variation in water quality and quantity occurring in streams across the Nation is natural and how much is caused by human activity.

The NASQAN network, which was begun in 1973, provides a basis for continuously assessing the quality of major rivers with respect to natural and man-induced factors. The network currently consists of 501 stations that are located in 331 subregional drainage basins, collectively encompassing nearly the entire Nation.

Figure 1. *Map of tidal Potomac River and Estuary. (Modified from fig. 4, U.S. Geological Survey Yearbook, Fiscal Year 1982, p. 75.)*


WASHINGTON, D.C.
Chain Bridge
Haines Pt
Anacostia River
Roosevelt Island
National Airport
Wilson Bridge
Tidal River
Piscataway Creek
Mattawoman Creek
Chicamuxen Creek
Quantico
Nanjemoy Creek
Transition Zone
MARYLAND
Aquia Creek
Port Tobacco River
Mathias Point
Morgantown
Lower Cedar Point
Wicomico River
Maryland Point
Potomac Creek
Rt 301 Bridge
Chaptico Bay
Cobb Island
Upper Machodoc Creek
St. Marys River
POTOMAC RIVER
CHESAPEAKE BAY
VIRGINIA
Nomini Bay
PINEY POINT
Estuary
Point Lookout
Smith Point
20 MILES
20 KILOMETERS
Study Area
CHESAPEAKE BAY
ATLANTIC OCEAN

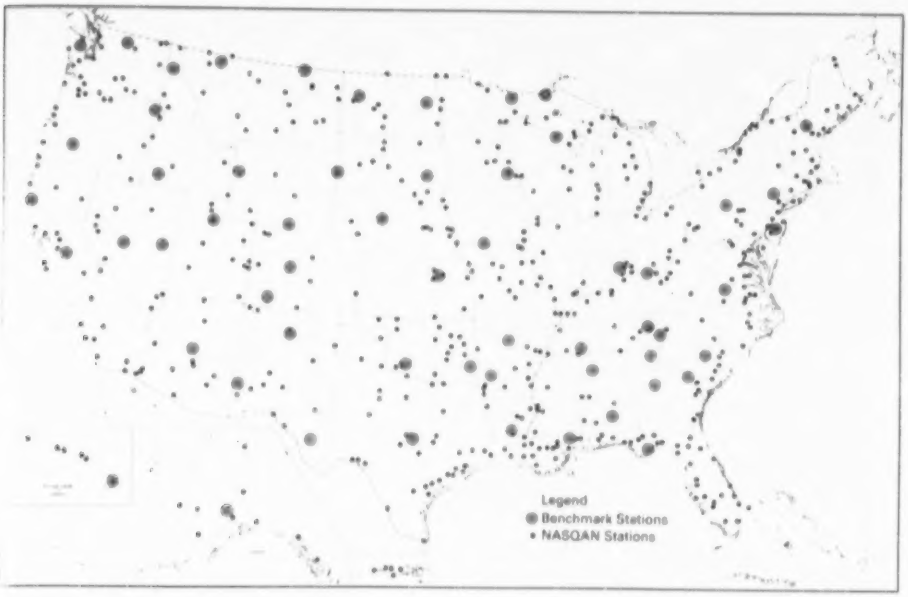


Figure 2. *Locations of stations in the Bench-Mark and NASQAN water-quality monitoring systems in operation as of September 30, 1984.*

Data routinely collected in the two networks include streamflow, concentrations of major inorganic and trace constituents (including heavy metals), bacterial indicators of pollution, and concentrations of several radiochemical constituents. A major purpose of both the Bench-Mark and NASQAN Networks is to detect trends in the concentrations of water-quality constituents. The problem of separating man-induced changes in water quality from the natural variability that results from seasonal change and differences between wet and dry years has complicated the analysis of data from these networks. However, Geological Survey scientists have recently developed new statistical techniques for detecting time trends in fixed-station water-quality data, and the techniques have proven successful for analyses of the constituents measured at the Bench-Mark and NASQAN stations. All trend analyses described in subsequent sections were conducted on water-quality data that were adjusted for the effects of flow and season.

Acid-Precipitation-Induced Trends at Bench-Mark Stations

The United States lacks long-term nationwide data on the chemistry of precipitation. Without these data, the next best possibility for detecting historic changes in precipitation chemistry is to evaluate trends in the chemistry of sensitive streams and lakes that might be attributable to changes in precipitation quality.

Records from the Bench-Mark Network are particularly appropriate for investigating atmospheric influences on water quality during the last decade because consistent sampling and analytical methods have been applied for a 10- to 15-year period at each network station and because the basins have been relatively unaffected by changes in land use. Many of the Bench-Mark Network streams have a low capacity to buffer acids, and these are expected to be sensitive to small changes in acid deposition.

Industrial emissions of sulfur dioxide are a major source of acidity in precipitation. Once emitted, the sulfur dioxide forms dilute sulfuric acid and is transported in the atmosphere. Thus, one expected result of increases in acid precipitation would be increases in the sulfate concentrations of streams. In contrast, alkalinity is a measure of the capability of water to neutralize acid and is, itself, reduced by the neutralization process. Hence, acid deposition would be expected to decrease alkalinity, especially where the initial concentration of alkalinity is low, as is typical in regions devoid of certain rock types, such as limestone and marble.

Figures 3 and 4 show the results of applying the new statistical techniques to detect trends in sulfate and alkalinity data collected over the past 10 to 15

Figure 3. *Trends in sulfate concentrations and in sulfur dioxide emissions at Hydrologic Bench-Mark stations. Arrows on the map point upward or downward to indicate the trend in sulfate concentrations. Dots indicate no significant trends detected. (Modified from U.S. Geological Survey Circular 910, 1983.)*

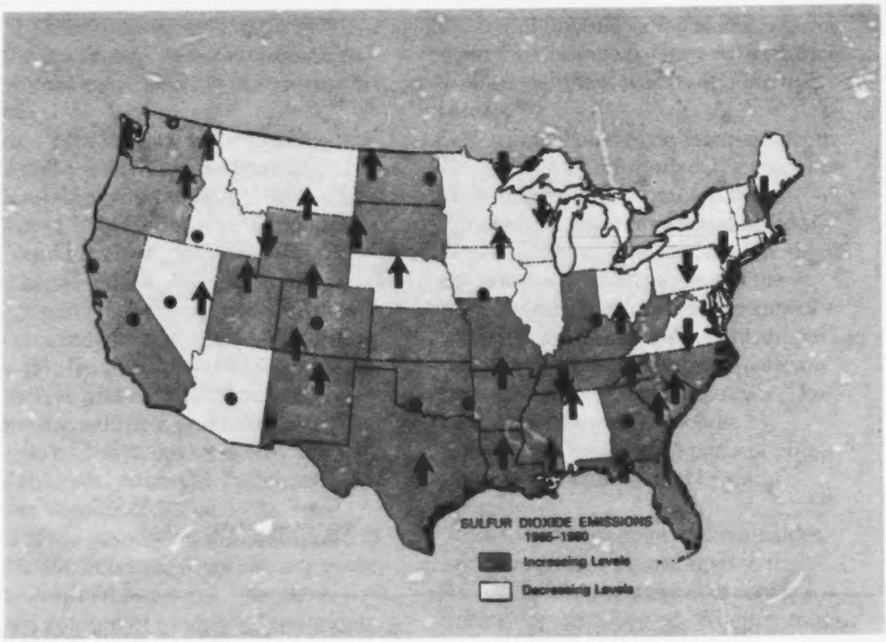
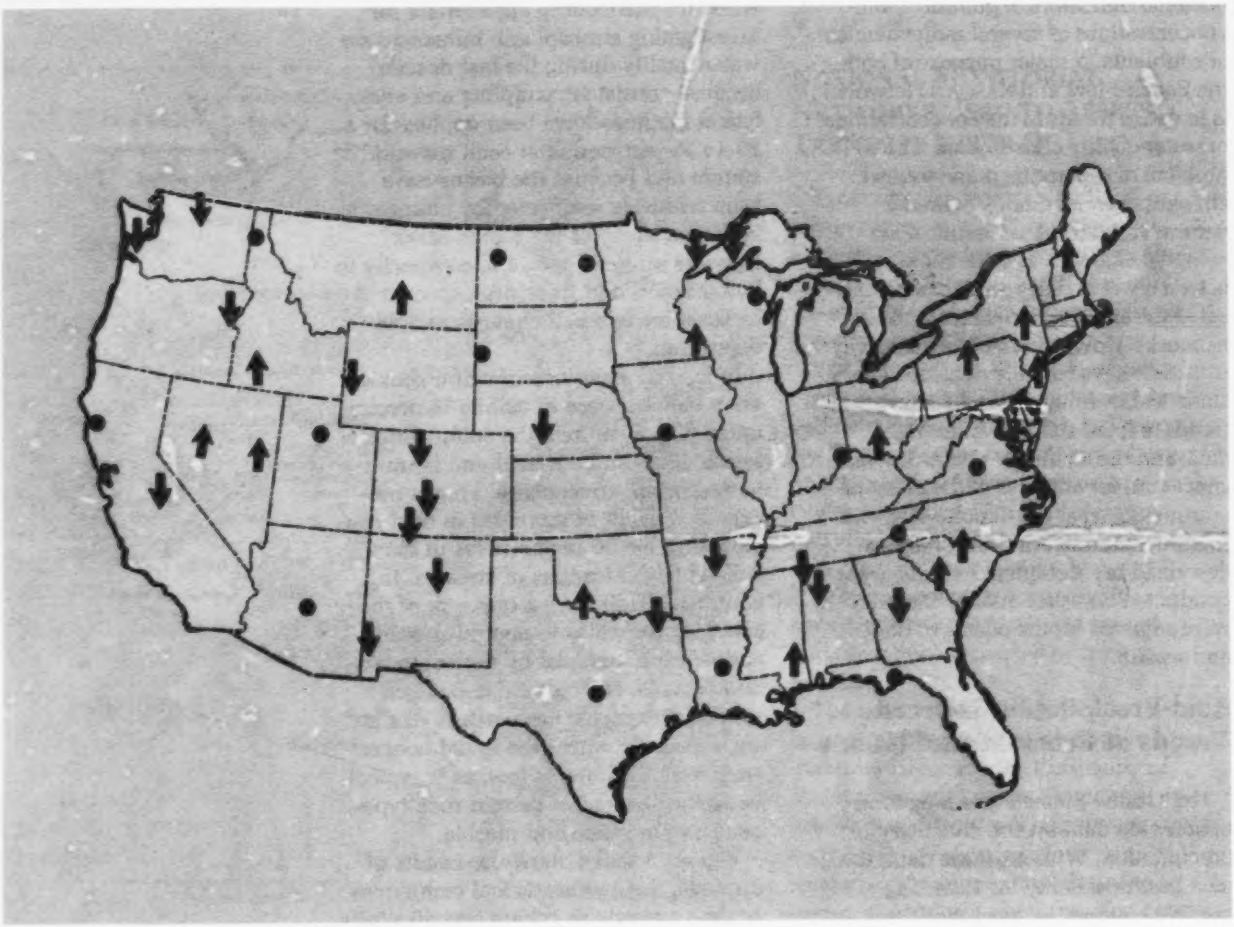

SULFUR DIOXIDE EMISSIONS
1966–1980
▨ Increasing Levels
☐ Decreasing Levels

Figure 4. *Trends in alkalinity concentrations at Hydrologic Bench-Mark stations. Arrows on the map point upward or downward to indicate the trend in alkalinity concentrations. Dots indicate no significant trends detected. (Modified from U.S. Geological Survey Circular 910, 1983.)*



years at Bench-Mark stations. Figure 3 also shows the direction of change in sulfur dioxide emissions (compiled by the U.S. Environmental Protection Agency) between 1965 and 1980.

Figure 3 shows that sulfate concentrations in streams have tended to increase during the last 10 to 15 years over a broad area of the continental United States, extending from the Southeast to the Mountain States and the Northwest. By contrast, streams in the Northeast have tended to show slight declines in sulfate concentrations. The overall geographical pattern is similar to that shown by trends in sulfur dioxide emissions to the atmosphere during the same period.

Figure 4 shows that downward trends in alkalinity, suggesting increases in the acidity of precipitation, greatly outnumber upward trends within a broad area from the Southeast to the Northwest. In contrast, alkalinity trends at the Bench-Mark stations in the Northeast are consistently upward, suggesting a decrease in the acidity of precipitation. The geographical distribution of trends in sulfate and alkalinity are consistent with the reported sulfur dioxide emissions. Together, the results suggest a decline in the acidity of precipitation in the Northeastern United States and an increase in acidity in most other regions during the last 10 to 15 years. The results also indicate that the effects of relatively small changes in atmospheric emissions are observable as changes in stream quality, a point that recently has been the focus of considerable national debate.

Trends in Suspended Sediment at National Stream Quality Accounting Network Stations

Although transport of sediment by flowing water is a natural process, excessive sediment is harmful to almost every beneficial use of water. Sediment fills reservoirs, clogs navigation channels, and drastically reduces the aesthetic and recreational values of rivers. Increased sedimentation, by raising the elevation of river-channel beds, can cause an increase in the frequency of floods. In the production of potable water, the cost of removing sediments generally exceeds the cost of all other treatment. Furthermore, other water contaminants, such as excess nutrients, toxic metals, and many of the pesticides, adhere readily to sediment particles and are transported, de-

John D. Powell (left) and Ronald R. H. Cohen (right) measuring dissolved oxygen, temperature, pH, and conductivity profiles in the tidal Potomac River from the U.S. Geological Survey Research Vessel Rockfish. *The Wilson Bridge is in the background. (Photograph by Daniel C. Hahl, Water Resources Division, U.S. Geological Survey.)*

best copy available

posited, and stored by suspended sediments.

Part of the sediment supplied to rivers arises from natural erosion, part from alterations to land from logging, farming, mining, and construction, and part from man-induced acceleration of river-channel erosion. Because of its importance, an analysis of trends in suspended sediment concentration has been made at those NASQAN stations that have sufficient long-term sediment data (R. A. Smith and R. B. Alexander, written communication, 1984). Nationwide, 225 such NASQAN stations have been established (fig. 5). Of these, the numbers of stations showing increasing and decreasing trends are nearly equal, but the trends at some important regional groupings of stations are predominatly in one direction or the other.

For example, there are a number of decreases in suspended-sediment concentrations in the Missouri Basin in Montana, North Dakota, and South Dakota. The specific stations showing decreases are located on the Missouri River mainstem as well as on tributaries including the Yellowstone, Knife, Cannonball, Grand, Belle Fourche, White, and James Rivers. Declining sediment concentrations previously have been reported for a number of locations in the Missouri Basin and have been attributed to the effects of reservoir construction throughout the basin during the 1950's and 1960's. Reservoirs act as sediment traps, and the effects of a new reservoir on downstream sediment concentrations may be observed for an extended period of time as a new equilibrium is established between the river forces that carry and deposit sediment.

Figure 5 shows that increases in suspended sediment concentrations have occurred in the Columbia Basin, Oregon and Washington; the Arkansas and Red River basins, Oklahoma; and the Mississippi Basin near the junctions of the Missouri and Ohio Rivers with the Mississippi mainstem. In all three cases, changes in land use activity appear to be the most likely causes of the uptrends.

It is likely that the trends detected in suspended-sediment concentrations at NASQAN stations may be associated with specific types of land use. The Geological Survey has compared the number and direction of detected trends to soil erosion information for three land uses—cropland, forest land, and range and pasture land—as compiled in the Natural Resources Inventory by the Soil Conservation Service. Although the ultimate validity of the comparison may depend on some still unknown factors, such as temporary or longer term storage of sediment, the present results show that suspended-sediment concentrations are increasing more than decreasing in basins dominated by sheet and rill erosion from cropland. In

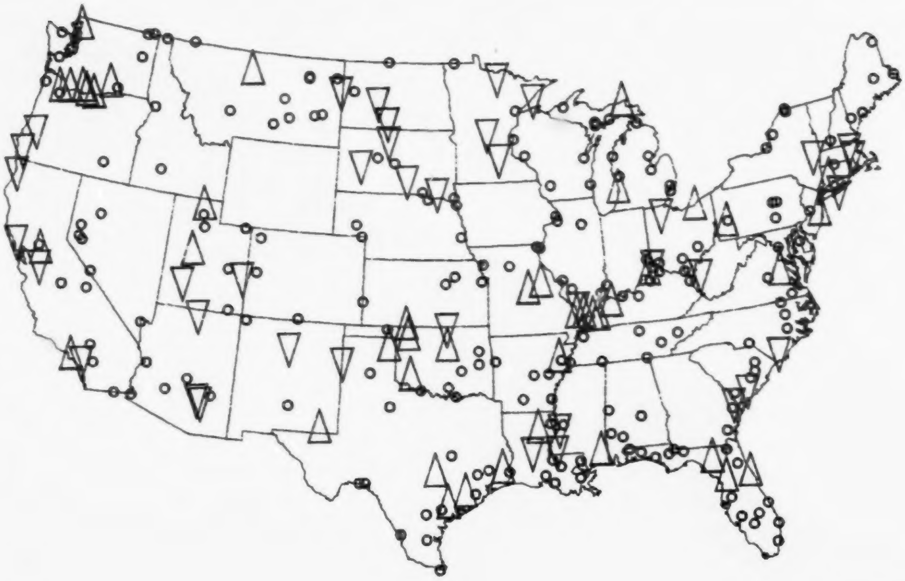


Figure 5. *Trends in suspended sediment concentrations at National Stream Quality Accounting Network stations, 1975 to 1981. Arrows on the map point upward or downward to indicate the trend in suspended sediment concentrations. Dots indicate no significant trends detected.*

contrast, suspended-sediment concentrations seem to be decreasing more than increasing in basins dominated by sheet and rill erosion from forest land, and the same also may be true in basins dominated by erosion from range and pasture land. These findings, if borne out by more detailed investigations, would have important implications for the planning of national erosion-control efforts.

GROUND-WATER CONTAMINATION

About one-half of the people in the United States rely on ground water for drinking water. In some places, such as Florida, New Mexico, and Long Island in New York, ground-water supplies more than 90 percent of the needs of the population. Because waste disposal is a common source of ground-water contamination, understanding the physical, chemical, and biological processes affecting the subterranean movement of contaminants is a key water-management issue. Physical processes that must be understood include the complex movement of ground water, the mixing of contaminants with the ground water, the filtration and sorption of contaminants by aquifer materials, and effects of buoyancy. The latter can result in contaminants concentrating at the top or the bottom of an aquifer, depending upon the density of the waste liquid. Chemical reactions can cause certain dissolved contaminants to join with other dissolved compounds to form new products that may be more toxic than their predecessors. In addition, bacteria and other microorganisms in ground water alter or decompose many organic ontaminants; here again, new products of greater toxicity can be created.

Our understanding of the processes affecting the movement and fate of ontaminants in ground water has ncreased significantly during the last everal years. However, a great deal more work needs to be done. Although ophisticated mathematical models have been developed to simulate many spects of contaminant movement and reaction in ground water, the methods to adequately measure all the parameters needed for these models have not been developed. Other areas in which we need to improve our understanding are ground-water flow in fractured-rock systems, ground-water flow in the unsaturated zone, and clay mineralogy.

Research Investigations at Selected Ground-Water Contamination Sites

In 1982, teams of scientists from the Geological Survey and universities, representing all major earth science disciplines, began studies of selected ground-water contamination sites to advance our understanding of processes affecting movement of contaminants in ground water. Selected for study were ground-water contamination from a crude oil pipeline break near Bemidji, Minnesota, ground-water contamination from the infiltration of creosote and pentachlorophenol (PCP) from waste-disposal pits at Pensacola, Florida, and ground-water contamination from the infiltration of domestic wastewater effluent on Cape Cod, Massachusetts. The types of contaminants at the three sites are associated with many ground-water contamination problems throughout the Nation. The studies are designed to improve our understanding of basic processes, and the knowledge gained will have practical transfer value to other sites having similar hydrogeologic conditions and types of contamination.

One of the research demonstration sites selected is an abandoned wood-treatment facility in northwest Florida. The 18-acre site, also a U.S. Environmental Protection Agency Superfund site, is located about 600 yards north of Pensacola Bay. During 80 years of continuous operation from 1902 to 1981, wastewaters generated from the use of creosote in the wood-treatment process were discharged into two unlined surface impoundments that are in direct contact with the sand and gravel aquifer, the principal source of water in northwest Florida. From 1902 to 1950, wood at the plant was treated exclusively with creosote. However, in 1950, PCP was introduced as a wood preservative at the plant, and its use steadily increased until the plant closed in 1981. Over the last few years of operation, the plant used about 25,000 gallons of creosote per month and a similar quantity of PCP.

Data collected at the site indicate that the ground-water contamination is confined to a volume generally less than 90 feet in depth (fig. 6) and extending less than 1,000 feet downgradient from the surface impoundments (fig. 7). Considering the 80 years of continuous waste discharge, the ground-water contamination has been confined to a much smaller part of the aquifer than would be expected for nonreactive contaminants at the estimated rate of ground-water flow. Laboratory and field studies have identified nearly 80 different organic contaminants in the ground water, some of which are readily bio-

Figure 6. *Vertical extent of ground-water contamination, as measured by total phenol (milligrams per liter), at an abandoned wood-treatment facility, Pensacola, Florida, 1982 to 1983.*

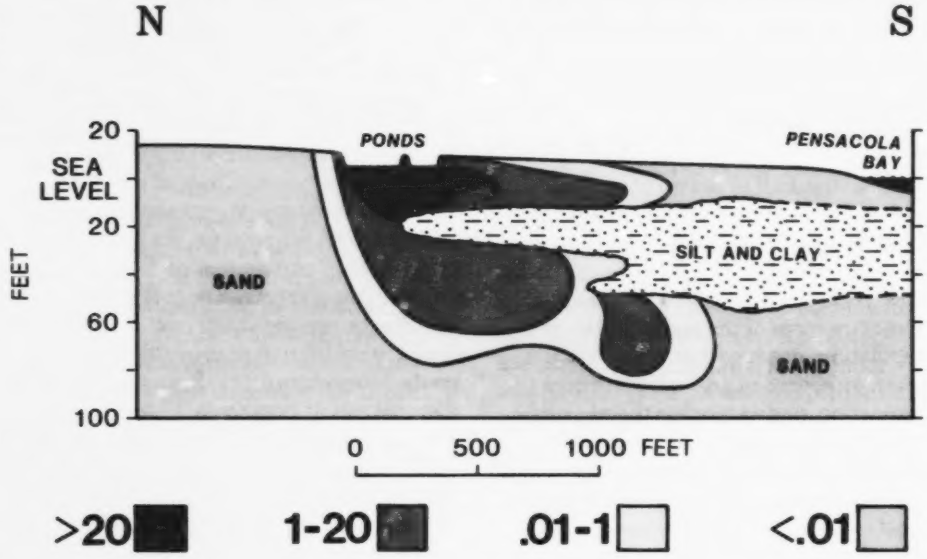
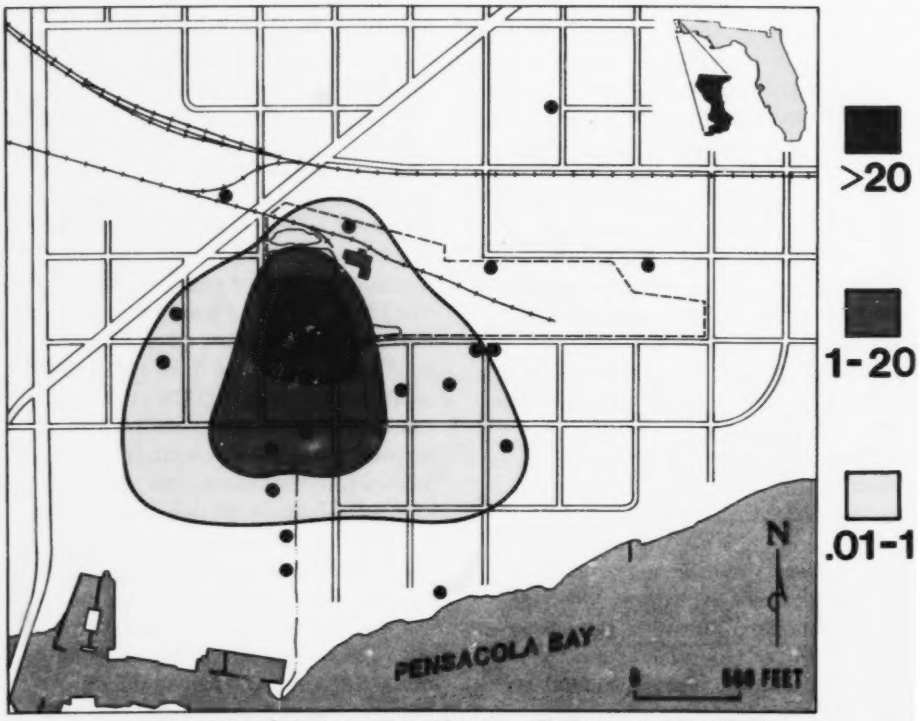

N
S
PONDS
PENSACOLA BAY
20
SEA LEVEL
20
60
100
FEET
SAND
SILT AND CLAY
SAND
0
500
1000 FEET
>20 ■
1-20 ■
.01-1 □
<.01 □

Figure 7. *Areal extent of ground-water contamination, as measured by total phenol (milligrams per liter), at an abandoned wood-treatment facility, Pensacola, Florida, 1982 to 1983.*


>20
1-20
.01-1
N
PENSACOLA BAY
0
FEET

20 FEET BELOW SEA LEVEL

degradable (H. C. Mattraw, oral communication, 1984). Five different water-quality zones have been characterized beneath the site, including a "bio-reaction zone" that seems to be the principal location where some of these organic compounds are degraded by microorganisms. Survey scientists are continuing specific research in each of these zones to better improve our understanding of the contaminant migration pathways, rates, controlling factors, and effects of the dominant chemical and biochemical processes.

NEW WATER-QUALITY STUDIES BY THE U.S. GEOLOGICAL SURVEY

Regional Ground-Water Quality

Unlike surface waters that can be relatively easily monitored to provide information about regional changes in water quality, ground water cannot be monitored efficiently by a network of stations. Such a network would be a costly and ineffective method of assessing the quality of the Nation's ground water because it moves slowly. The volume of contaminated ground water is usually small, and it tends to occur in slowly developing pockets around point sources of contamination or in shallow, slowly expanding zones beneath areas of nonpoint pollution. Thus, a monitoring strategy in which samples are collected from observation wells chosen for areal coverage would fail to detect most developing contamination problems until a great deal of damage had been done.

As an alternative to fixed-station monitoring, the Geological Survey has begun a series of 14 regional ground-water quality studies to provide information on ambient ground-water chemistry with emphasis on organic substances and trace elements and to identify the causes, effects, and processes that are applicable to similar areas elsewhere. Study areas vary in size from a few tens of square miles to a few thousand square miles. Each area is characterized by relatively uniform climatic and geohydrologic conditions, and the land use, the ground-water flow system, and the inorganic chemical quality of the ground water generally are well understood. Although results from these studies are not expected for several years, careful analyses to determine the factors affecting the quality of our ground water may allow extrapolation of these results to the national level.

Toxic Substances in Surface Waters

Water contamination by dioxin at Times Beach, Missouri, kepone in the lower James River, Virginia, and polychlorinated biphenyls in the Hudson River in New York State have heightened the public's awareness of toxic substances in surface waters. In fact, because ground-water and surface-water systems are connected hydrologically, it is important that, in addition to understanding the processes affecting toxic substances in ground water, we understand the sources, distribution, transport, and fate of these substances in rivers, lakes, and estuaries.

During the past 25 years, the Geological Survey has conducted many individual studies of toxic substances in surface waters. Recently, a program has been started to increase our understanding of the processes affecting the movement and fate of different groups of toxic substances under different hydrologic conditions and to describe the occurrence, magnitude, and distribution of toxic substances in surface waters, bottom sediments, and aquatic biota and how these substances are changing with time. The new program consists of three integrated components—research, river basin investigations, and monitoring.

Much of the research is dedicated to the development of information on the migration pathways, rates, and controlling factors of the processes by which toxic substances move and undergo chemical and biochemical changes in rivers and to the development of improved study approaches, sampling methods, and analytical techniques.

The purpose of the river basin investigations is to develop an understanding of the movement and fate of specific classes of toxic substances under different hydrologic conditions. In addition, the river basin investigations will uncover locations and types of toxic contamination in rivers. This will dictate future monitoring needs concerning whether the concentrations of specific substances are increasing or decreasing and how long certain compounds remain in river systems after sources have been controlled.

Finally, the monitoring component of the program, beginning with sediments, will provide a broad view of the occurrence and distribution of toxic substances in the Nation's rivers. Analyses of the data from the monitoring efforts are expected to uncover additional needs for process-oriented research that will help identify candidate watersheds for future river basin investigations.

Sound technical information about the quality of the ground and surface water is essential in meeting the Nation's water-resources needs, in using the land wisely, and in preserving the quality of the environment. The Geological Survey will continue to provide the hydrologic data and understanding of hydrologic processes needed to make the fundamental decisions on the future water needs of the Nation.

The Continued Rise of Great Salt Lake, Utah

The Great Salt Lake rose 5.0 feet from September 25, 1983, to July 1, 1984, the second largest seasonal rise on record since 1847. The maximum seasonal rise was observed the previous year when the lake rose 5.1 feet from September 18, 1982, to June 30, 1983. The lake declined only 0.5 foot during summer 1983; thus, the net rise from September 18, 1982, to July 1, 1984, was 9.6 feet. By comparison, the previously recorded maximum net rise over a similar period of time was 4.75 feet from 1970 to 1972.

The lake has a yearly cycle (fig. 1). The level begins to decline in the spring or summer when the weather is hot enough so that the loss of water by evaporation from the lake surface is greater than the inflow from surface streams, ground water, and precipitation directly on the lake. It begins to rise in the autumn when the temperature decreases, and the loss of water by evaporation is exceeded by the inflow. According to past records, the rise can begin at any time between September and December, and the decline, at any time between March and July.

The level of the lake surface and the volume of the lake reflect an instantaneous equilibrium between the inflow and the loss by evaporation. The surface area and brine concentration are the major aspects of the lake that affect the volume of evaporation. During dry years, the water level declines, causing a decrease in surface area; consequently, the volume of evaporation decreases. As the lake declines, the brine generally becomes more concentrated, which decreases the rate of evaporation. During wet years, the water level rises, causing an increase of surface area; consequently, the volume of evaporation increases. As the lake rises, the brine generally becomes less concentrated, which increases the rate of evaporation.

Precipitation was above average during summer 1983, and evaporation was relatively small because of greater-than-normal cloud cover. This resulted in an unusually small decline of lake level during the summer. By September 25, when the seasonal rise began, the lake level had declined only 0.5 foot. The excessive precipitation continued throughout the autumn and culminated in the wettest December ever recorded in Salt Lake City. By New Year's Day, Salt Lake City had recorded 24.26 inches of precipitation during the past year—about 1.6 times the average.

The cumulative precipitation during the first one-half of 1984 also was above average, and, from October 1983 through June 1984, the precipitation at

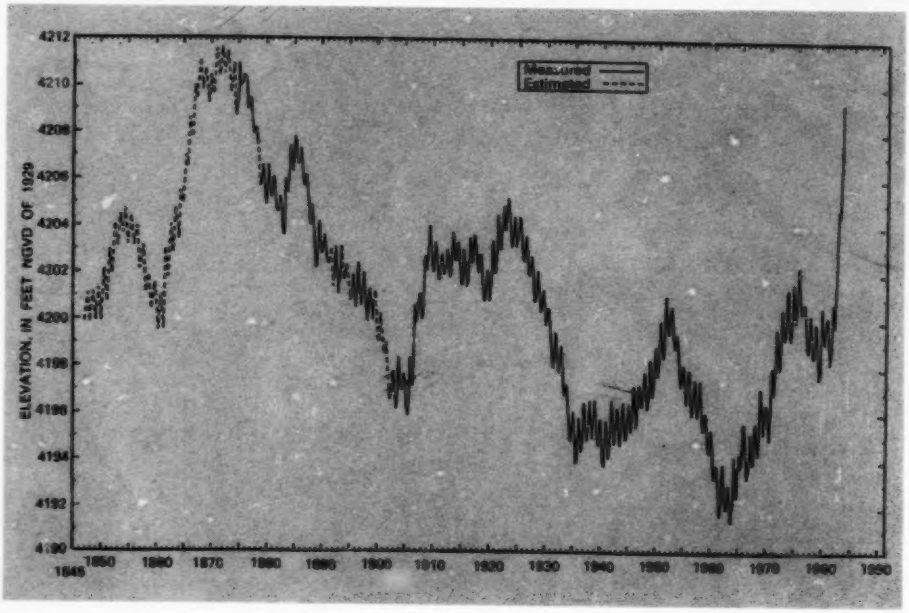


Figure 1. *Fluctuations of the water level of Great Salt Lake.*

the Salt Lake City Airport was about 1.5 times greater than average. Much of the precipitation fell in the form of snow on the mountains in the drainage basin. The snowmelt began soon after May 1, at which time the snow cover ranged from about 1.2 to 1.5 times greater than average in the Bear River basin, about 1.5 times greater than average in the Weber River basin, and from about 1.3 to 1.8 times greater than average in the Jordan–Provo River basin.

The lake rose steadily from October 1983 through June 1984, and one of the major contributing factors that resulted from the excessive precipitation was the inflow in three major surface tributaries. The measured inflow during that period, which accounts for more than 90 percent of the total from the three tributaries, was about 3.1 million acre-feet in the Bear River, 923,000 acre-feet in the Weber River, and over 1.2 million acre-feet in the Jordan River. The flow in the Bear River was about 2.7 times greater than average; in the Weber River, about 2.1 times greater than average; and in the Jordan River, about 5.2 times greater than average.

When the lake peaked on July 1, 1984, it was at a level of 4,209.25 feet above sea level. The increase in area covered by the lake during its 5-foot rise since September 25, 1983, was about 210,000 acres (330 square miles). This resulted in continuing damage to the roads, railroads, wildfowl-management areas, recreational facilities (fig. 2), and industrial installations that had been established on the exposed lakebed. The Utah Division of Water Resources estimates that the capital damages at these facilities as the lake rose the 5 feet was about $150 million. The Geological Survey continues to work with State and local authorities to provide information that can be used to mitigate damages from rising lake levels.

Figure 2. *Saltair, a huge dance and recreational pavillion, being submerged by the Great Salt Lake. Water covered the dance floor to a depth of more than 1 foot on April 11, 1984, as the lake level reached 4,207.7 feet. The lake peaked at 4,209.25 feet on July 1, 1984. (Photograph by Ted Arnow, Water Resources Division, U.S. Geological Survey.)*

Movement and Fate of Contaminants From Treated Sewage Infiltrated to Ground Water, Cape Cod, Massachusetts

Understanding the movement of contaminants from waste-disposal sites through a ground-water system is important to the protection of water supplies. A contaminant introduced to ground water generally will move with it but may adsorb onto the aquifer materials or may react, either chemically or biologically, to form other, possibly less harmful, products. A contaminant moving with ground water also tends to disperse and becomes less concentrated due to nonuniform flow velocities and to the complex branching of flow in an aquifer. Dispersion will reduce the maximum concentration of a contaminant but will increase the volume of contaminated water.

Since 1936, secondarily treated domestic sewage has been discharged to the ground on surface sand beds at a sewage-treatment plant at Otis Air Force Base, Massachusetts. Infiltration of the sewage through sand beds to an underlying sand and gravel aquifer and the subsequent movement of the sewage-contaminated ground water in a southerly direction have caused a plume of contamination to form that is 3,000 feet wide, 75 feet thick, and more than 11,000 feet long.

The extent of the plume can be defined by chemically analyzing water sampled from the aquifer or by geophysical techniques. Ions (charged particles) of boron, chloride, and sodium and detergents that are known to occur at much higher concentrations in sewage than are found normally in the local ground water make good indicators of plume location. Increasing the dissolved ions in water increases its electrical conductivity. Because of the elevated level of dissolved ions, the plume is detectable, from instrumentation on the land surface, by a number of methods for measuring electrical conductivity of the soil, the aquifer, and the ground water.

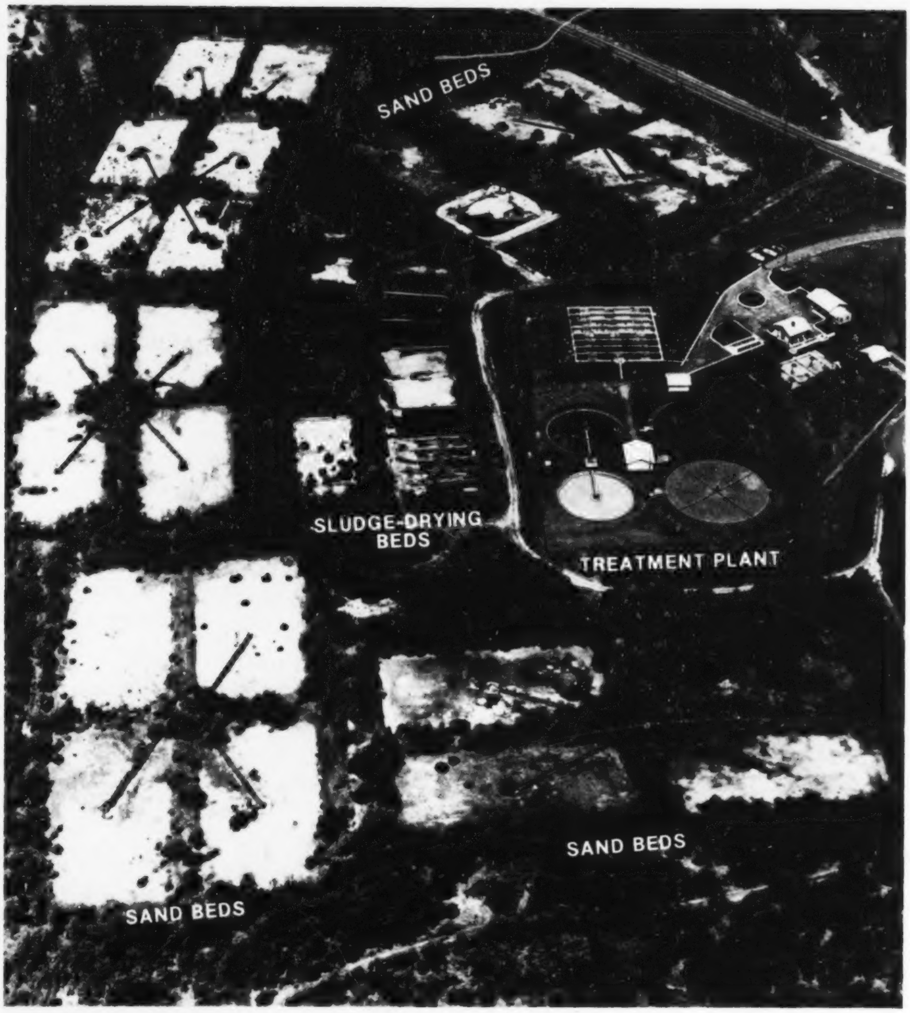
In 1977, the U.S. Geological Survey, in cooperation with the Massachusetts Department of Environmental Quality Engineering, Division of Water Pollution Control, began a study to describe the extent and chemical composition of the zone of ground water contaminated by the sewage disposal at Otis Air Base to better understand the potential for ground-water contamination at other similar waste-disposal sites. The field data collected from this first study, released as Open-File Report 82–274, *Sewage Plume in a Sand and Gravel Aquifer, Cape Cod, Massachusetts*, by D. R. LeBlanc, provided one of the best three-dimensional descriptions of a contaminant plume available at that time. That description, and the results from a subsequent study, demonstrated the potential of this site to advance scientific understanding of the processes that control convective dispersion transport and chemical change of contaminants in a plume. In March 1983, the Otis site was proposed, and later accepted, for a major research study of these topics. Some results from the first year of the research study follow.

Most contaminants move readily through the sand and gravel that make up the aquifer on Cape Cod, and little discernible attenuation by sorption of solutes on the aquifer material is evident. Transverse and longitudinal spreading of the plume is significant, but little vertical mixing occurs. After 10,000 feet of movement, the plume is only about 75 feet thick, with a core zone 20 to 30 feet thick where the contaminants remain at concentrations more than one-fourth of what they are in the treated sewage.

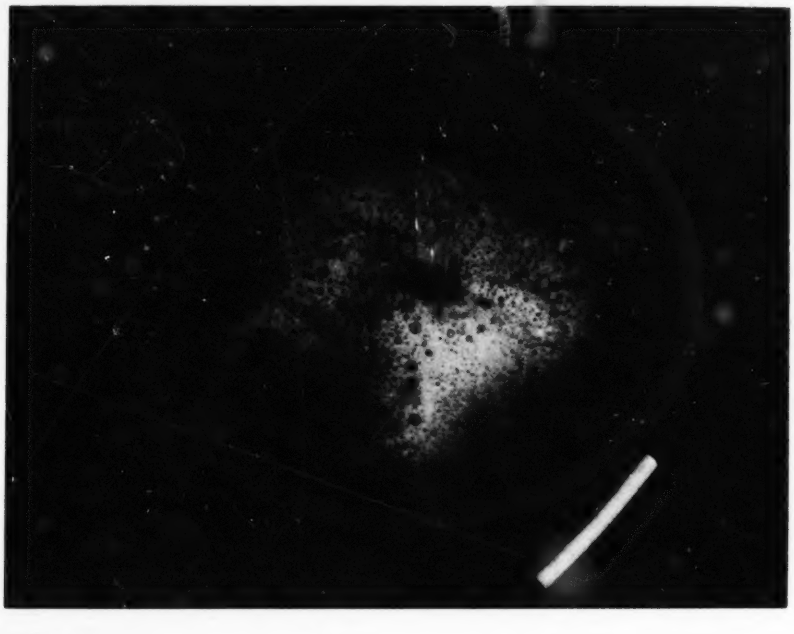
Microbiological reactions affect some contaminants in the plume. For example, a high concentration of nitrogen in the form of nitrate is present in the treated sewage. Within a few tens of feet in the direction of ground-water flow from the infiltration beds, nitrate is found at a much lower concentration, but ammonia is present. At 1,000 feet downgradient, no nitrate is found in the core of the plume, but ammonia concentrations exceed 10 milligrams per liter. At 5,000 feet downgradient, nitrate is again found in the core but no ammonia.

Dissolved organic carbon decreases more rapidly with increasing distance

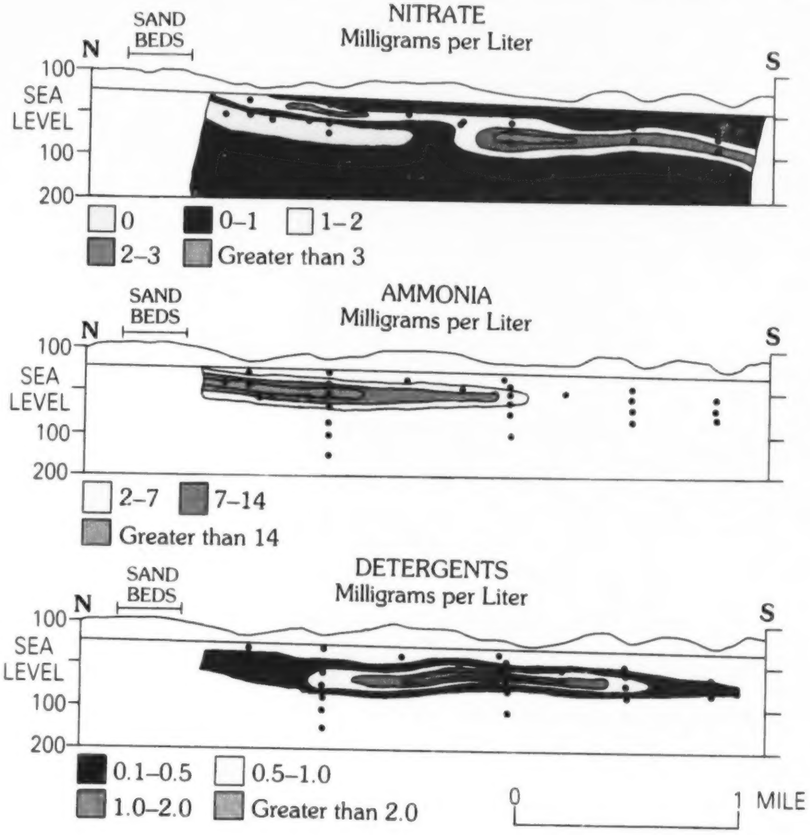
The Otis Air Force Base sewage-treatment plant and sand beds. Secondarily treated domestic sewage has been discharged to the ground on surface sand beds since 1936. (Photograph courtesy of the U.S. Air National Guard.)


SAND BEDS
SLUDGE-DRYING BEDS
TREATMENT PLANT
SAND BEDS
SAND BEDS

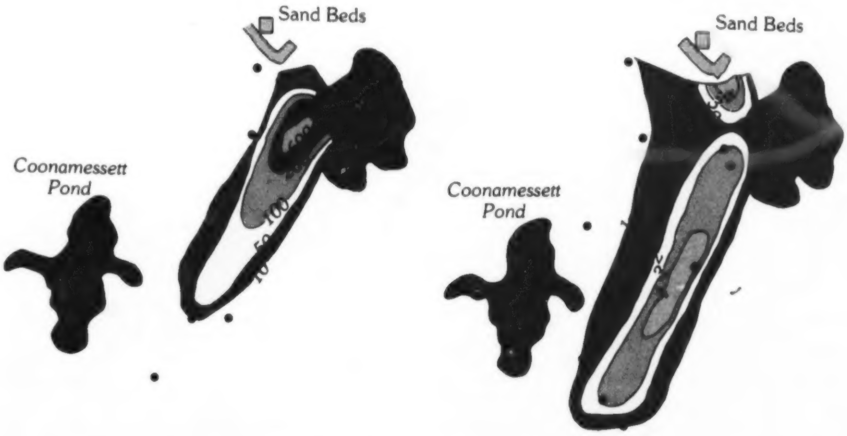
Bucket of foaming water taken from a well in the contaminant plume. Most dissolved organic carbon, present in the plume beyond 1,500 feet from the point of infiltration, may be nonbiodegradable detergents. (Photograph by Denis R. LeBlanc, Water Resources Division, U.S. Geological Survey.)



from the source than do conservative contaminants, such as chloride, sodium, and boron. Most dissolved organic carbon, present in the plume beyond 1,500 feet from the point of infiltration, may be nonbiodegradable materials, such as detergents. Microbial populations are distributed in the plume in a manner consistent with the distribution of changes in water quality. The number of free-living bacteria declines linearly with respect to distance from the point


NITRATE
Milligrams per Liter
SAND BEDS
N
S
100
SEA LEVEL
100
200
0
0–1
1–2
2–3
Greater than 3
AMMONIA
Milligrams per Liter
SAND BEDS
N
S
100
SEA LEVEL
100
200
2–7
7–14
Greater than 14
DETERGENTS
Milligrams per Liter
SAND BEDS
N
S
100
SEA LEVEL
100
200
0.1–0.5
0.5–1.0
1.0–2.0
Greater than 2.0
0
1 MILE

Concentration of nitrate and ammonia, expressed as nitrogen, and detergents, in milligrams per liter, in a longitudinal section in the contaminant plume. Ground-water flow is to the right.


Sand Beds
Coonamessett Pond
400
100
50
10
Sand Beds
Coonamessett Pond
1

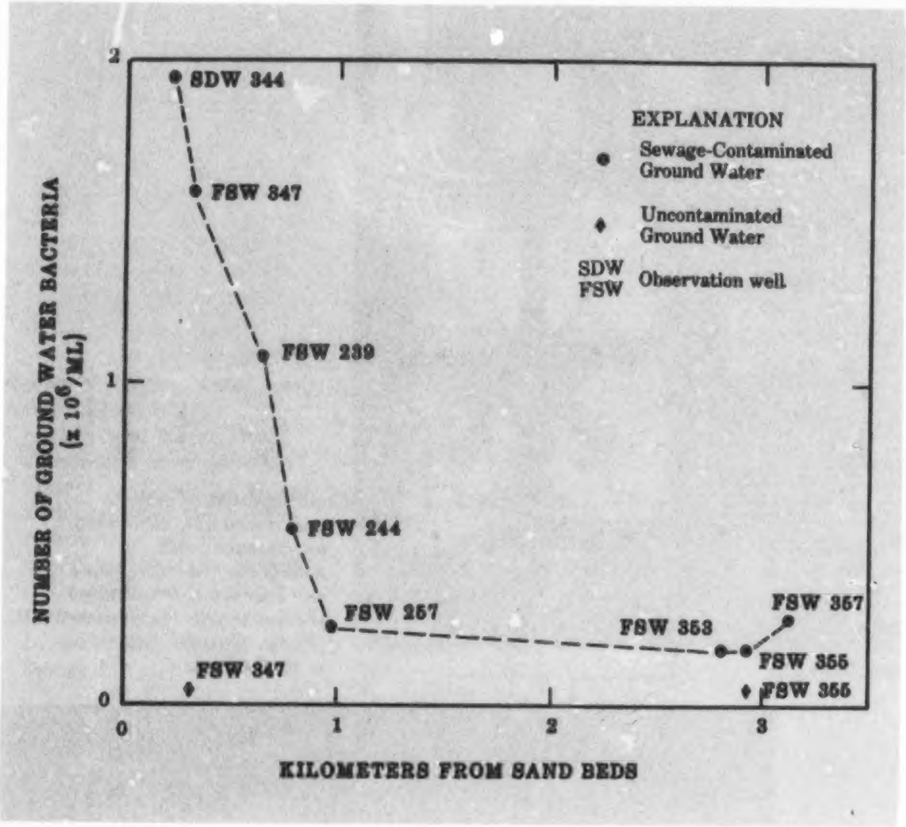
VOLATILE ORGANICS
Micrograms per Liter

DISSOLVED ORGANICS CARBONS
Milligrams per Liter

Concentration of volatile organics and dissolved organic carbon in the contaminant plume. Ground-water flow is to the lower left.

of infiltration to a point about 1/2-mile downgradient, whereafter they continue to be found at a low and relatively constant level. Bacteria fixed to the aquifer material are probably more significant than the free bacteria in causing the observed reactions.

Computer models that simulate the movement of solutes in an aquifer have been applied successfully to the plume. A two-dimensional model was used to simulate the horizontal spreading of several contaminants in the plume. However, the physical properties of the aquifer that affect dispersion still are not well understood, and such knowledge may be critical to the ability to model the plume in three dimensions. Further study of this sewage plume on Cape Cod will assist in understanding the migration of contaminants in ground-water systems nationwide.



Bacterial counts in the contaminant plume decline in relation to distance from the sand beds where the treated sewage is infiltrated.

Screening of Geohydrologic Environments in the Basin and Range Province for High-Level Radioactive Waste Disposal

Deeply buried repositories in specially constructed mines offer several properties suitable for disposal of high-level radioactive waste. Principal among these properties are adequate shielding, isolation from the environment, absorption and dispersion of heat generated by the radioactive waste, and protection from intrusion by man. The potential for migration of high-level radioactive wastes from the repository demands that attention be given not only to the selection of a suitable host material for the waste—the rock in which the repository is to be constructed—but also to the selection of the geohydrologic environment of the repository. Ideally, the geohydrologic environment best suited for a high-level radioactive waste-disposal site would have many natural barriers to waste movement. These barriers include the following:

- Rock through which water moves very slowly (low permeability);
- Ground-water flow away from the biosphere;
- Long flow paths to points readily accessible to people;
- Little water movement and great thickness of the unsaturated zone above the water table;
- Low rainfall;
- Strong host rock with few fractures;
- Small probability of seismic or volcanic activity;
- Slow rate of erosion;
- Ground-water chemistry favoring low radionuclide solubility; and
- High capacity for adsorption (sorption) or ion exchange of waste radionuclides.

In view of the numerous combinations that are possible among the various natural barriers, the identification of suitable geohydrologic environments dictates that site selection for a high-level radioactive waste repository be approached using comprehensive analysis. The process used by the U.S. Geological Survey is described below.

The Geological Survey's program for identifying potential environments suitable for locating acceptable repositories in the Basin and Range province was an outgrowth of a plan developed jointly with the U.S. Department of Energy, which has the responsibility for selecting, building, and operating the repositories. The Geological Survey assists the Department of Energy by providing fundamental geohydrologic information to be used in solving the Nation's problem of selecting high-level radioactive waste-disposal sites. Although this is a Geological Survey study, earth scientists from the particular States involved are participating actively.

The screening process consists of several stages. At each stage, it involves geologic and hydrologic description and evaluation of successively smaller land units. According to the plan, the Basin and Range province was divided into smaller land units that were ranked as follows: First, regions (10^3–10^5 square miles); second, areas (10^2–10^3 square miles); and third, potential sites (about 10 square miles).

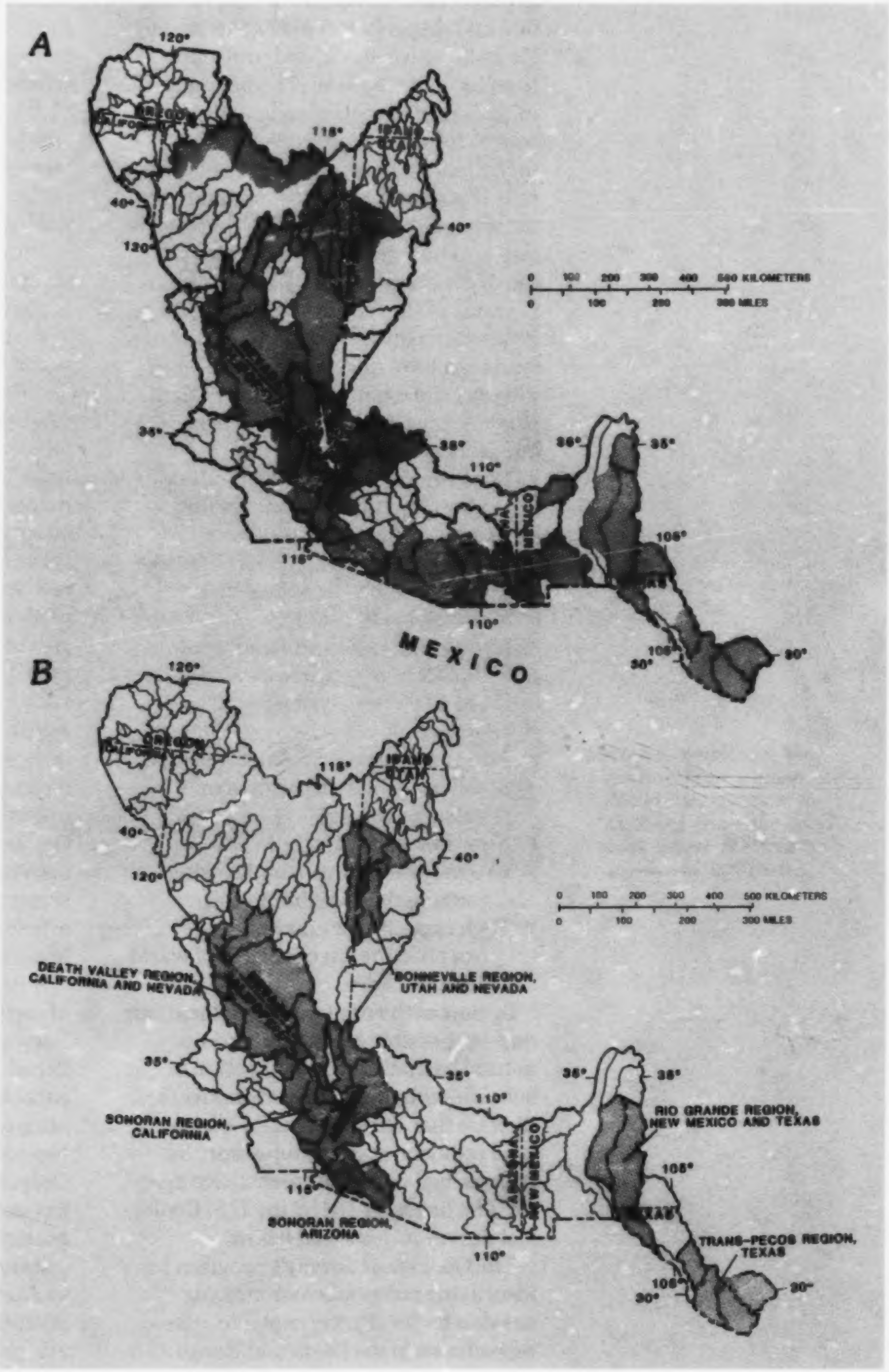
Screening of the province and regions is based only on existing data. Field work and collection of new data are not part of the present study. A screening program based on nongeologic factors, such as socioeconomic considerations, is also important in choosing areas for further study to select a site for the disposal of radioactive waste. Such a program would be managed by the U.S. Department of Energy and would be used in conjunction with the geologic screening program described in this article in selecting areas for field investigations.

A Province Working Group, composed of earth scientists from the Geological Survey and several States, was established. The States that are formally participating in the province screening program are Arizona, California, Idaho, Nevada, New Mexico, Texas, and Utah. Oregon is kept informed of progress and has participated informally by reviewing geologic maps.

Basic factors selected for province evaluation were the distribution of potential host rocks, tectonic stability, and ground-water hydrology. Geologic data to be evaluated include information on the following:

- Distribution of rock types considered to be potential host rocks. Surface outcrops of basalt, granitic rocks, argillaceous rocks, tuff, salt, and anhydrite were mapped. In addition, data on subsurface occurrences of salt and anhydrite were compiled;
- Seismicity;
- Quaternary volcanism;
- Quaternary faulting;
- Heat flow; and
- Mineral and energy resources.

Hydrologic data to be evaluated include

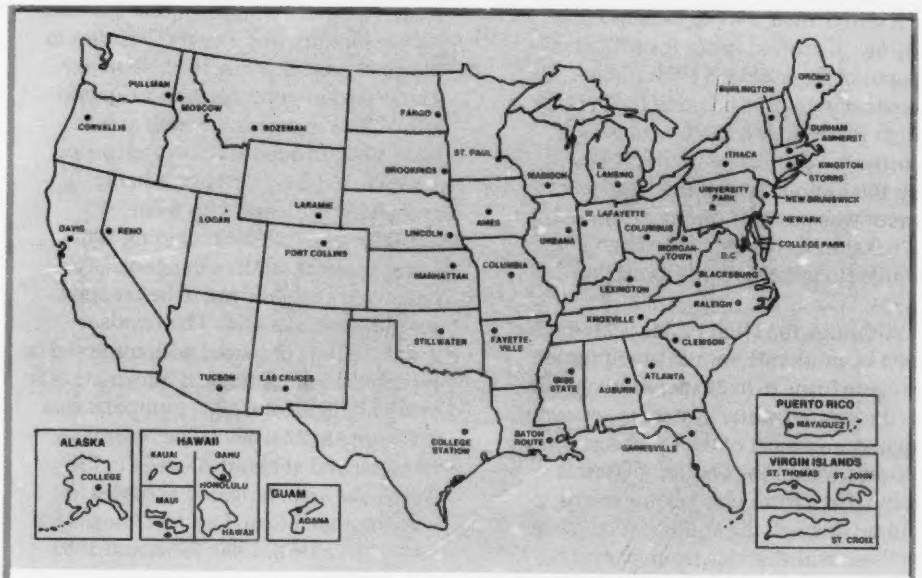

A
120°
OREGON
CALIFORNIA
115°
IDAHO
UTAH
40°
120°
40°
0 100 200 300 400 500 KILOMETERS
0 100 200 300 MILES
35°
35°
110°
35°
35°
ARIZONA
NEW MEXICO
105°
TEXAS
115°
110°
MEXICO
105°
30°
30°
B
120°
OREGON
CALIFORNIA
115°
IDAHO
UTAH
40°
40°
120°
0 100 200 300 400 500 KILOMETERS
0 100 200 300 MILES
DEATH VALLEY REGION, CALIFORNIA AND NEVADA
BONNEVILLE REGION, UTAH AND NEVADA
35°
35°
35°
35°
110°
SONORAN REGION, CALIFORNIA
RIO GRANDE REGION, NEW MEXICO AND TEXAS
ARIZONA
NEW MEXICO
105°
115°
TEXAS
SONORAN REGION, ARIZONA
TRANS-PECOS REGION, TEXAS
110°
105°
30°
30°

Basin and Range province. A, Prospective land units for favorable high-level radioactive waste-isolation environments. B, Regions selected for further study.

information on the following:

- Ground-water flow;
- Potentiometric surface;
- Chemical quality of ground water;
- Natural ground-water discharge areas;
- Depth to water table. This information is to be used to define the thickness of the unsaturated zone, an environment in which various rock types might be acceptable as host media; and
- Water use.

The process of the screening of the region by the Province Working Group resulted in the identification of land units considered to be prospective for containing geohydrologic environments for the isolation of high-level radioactive waste (*A* part of the figure). Of these land units, regions were selected for further study and are shown in the *B* part of the figure. The province phase of screening is discussed in detail in a series of three reports, released as U.S. Geological Survey Open-File Reports 83–759, 83–699, and 83–756, which are pending publication in the Circular series as 904–A, 904–B, and 904–C. Currently, the program is screening the regions shown in the figure. The evaluation of the regions and the identification of areas that are prospective for further study will complete the study.


PULLMAN
MOSCOW
CORVALLIS
BOZEMAN
FARGO
ST. PAUL
BROOKINGS
LARAMIE
LOGAN
DAVIS
RENO
FORT COLLINS
LINCOLN
AMES
MANHATTAN
COLUMBIA
STILLWATER
FAYETTEVILLE
TUCSON
LAS CRUCES
COLLEGE STATION
MADISON
E. LANSING
URBANA
W. LAFAYETTE
COLUMBUS
MORGANTOWN
LEXINGTON
KNOXVILLE
MISS STATE
AUBURN
ATLANTA
CLEMSON
BATON ROUTE
GAINESVILLE
ORONO
BURLINGTON
DURHAM
AMHERST
KINGSTON
STORRS
ITHACA
UNIVERSITY PARK
NEW BRUNSWICK
NEWARK
COLLEGE PARK
D.C
BLACKSBURG
RALEIGH
ALASKA
COLLEGE
HAWAII
KAUAI
OAHU
HONOLULU
MAUI
HAWAII
GUAM
AGANA
PUERTO RICO
MAYAGUEZ
VIRGIN ISLANDS
ST. THOMAS
ST JOHN
ST CROIX

WATER RESOURCES RESEARCH INSTITUTE PROGRAM

In October 1983, the U.S. Geological Survey assumed responsibility for the administration of the Water Resources Research Institutes. The map shows the 54 institutes, located at land grant universities in each State, Guam, Puerto Rico, the Virgin Islands, and the District of Columbia, that are supported by Federal and State funds. This national network of institutes

- Works with local, State, and regional water interests to identify critical water-related problems;
- Conducts research aimed at the solution of those problems;
- Trains students in water sciences through research support; and
- Develops and distributes water resources information.

Research at the institutes is addressing problems such as

- Ground-water contamination;
- Nonpoint pollution;
- Acid precipitation;
- Ground-water depletion; and
- Management of water supply.

Results of the research are communicated to the user community through

- Technical reports;
- Professional literature;
- Workshops, seminars, and conferences; and
- Newsletters.

High Plains Regional Aquifer System Analysis—Phase II Activities

The High Plains is a 174,000-square-mile area of flat to gently rolling terrain east of the Rocky Mountains. It includes parts of Colorado, Kansas, Nebraska, New Mexico, Oklahoma, South Dakota, Texas, and Wyoming. The High Plains is underlain by unconsolidated alluvial deposits that form a water-table aquifer capable of sustaining well yields of 100 to more than 1,000 gallons per minute. Irrigation from this aquifer has made the High Plains one of the Nation's leading agricultural areas.

Around 1940, a rapid expansion in the use of ground water for irrigation began in the southern High Plains; this expansion in use spread to the central High Plains in the 1950's and to the northern High Plains in the 1960's. By 1980, about 18 million acre-feet of water was pumped annually from about 170,000 wells drilled in the High Plains aquifer to irrigate about 13 million acres.

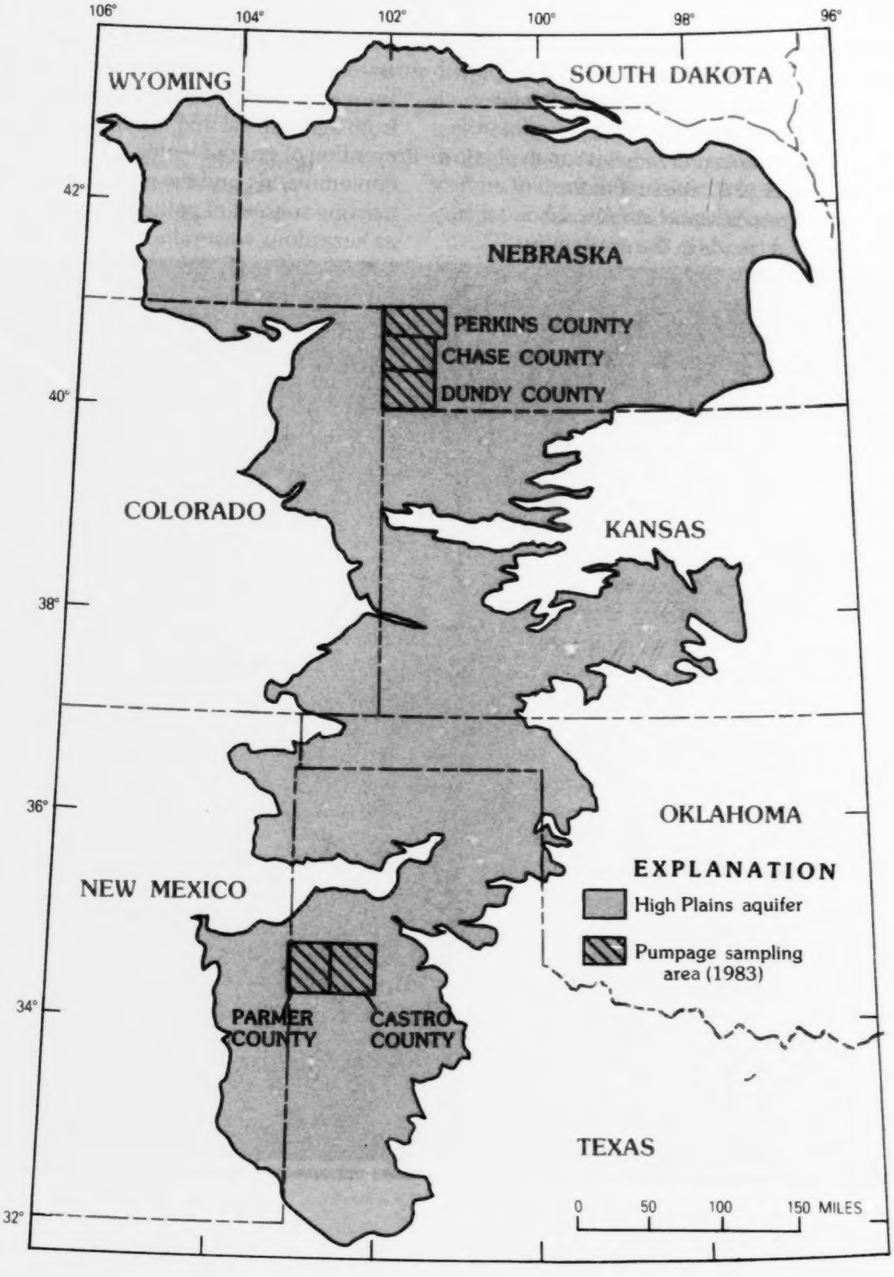
Although the High Plains is characterized by moderate annual precipitation ranging from 16 to 28 inches, recharge to the ground-water system is generally sparse, and most of the pumpage is from storage within the aquifer materials rather than from water being transmitted through the aquifer. As a result of these withdrawals from storage, widespread declines in water levels have occurred so that the aquifer has been dewatered by more than 50 percent of its saturated thickness in over 3,500 square miles in Kansas, New Mexico, and Texas. These water-level declines have increased the cost of water to irrigators because increased pumping lifts cause higher energy costs and have reduced well yields because of a decrease in the saturated thickness of the aquifer materials.

In 1978, The U.S. Geological Survey began a study of the High Plains aquifer as part of the Regional Aquifer System Analysis Program to understand the flow system and to evaluate the effects of the irrigation development on a regional scale. This study, completed in 1982, indicated that data on pumpage for irrigation and recharge to the aquifer from irrigation return flow are essential to evaluate water-level declines due to irrigation development; these data, however, were not readily available. To develop a method of estimating these data with an acceptable confidence level, a follow-up project to the program, Phase II, was started in 1983.

Two areas, shown on the accompanying illustration, have been selected for these studies. One area includes Castro and Parmer Counties in the southern High Plains of Texas; the other includes Chase, Perkins, and Dundy Counties in the northern High Plains of Nebraska. The period of pumpage and irrigation return-flow analyses for each area is from 1974 through 1983—10 irrigation seasons. Irrigated acreage is being mapped in both areas for even-numbered years (and including 1983) using Landsat satellite imagery. Dry land and rangeland are to be mapped for the Nebraska area. The Landsat maps will be compared with observed or reported acreage maps, if information is available. The total 1983 pumpage was measured at 52 wells at the Nebraska test area and at about 86 wells in the Texas test area. Irrigated acreages are being mapped from Landsat images for 1974, 1976, 1978, 1980, 1982, and 1983 for the Nebraska and Texas areas. About one-half of the maps showing irrigated land have been completed.

Data on pumpage and irrigated acreage have been collected for about 50 irrigation systems in each area for the 1983 and 1984 irrigation seasons and will be used as the key information upon which pumpage for the entire test area will be estimated. In the Nebraska area, nearly all wells are equipped with in-line volumetric flowmeters. These measured flow data also will be used to check the accuracy of flow data measured by portable flowmeters. In the Texas area, pumpage will be measured solely by portable flowmeters and time-of-operation sensors that will be calibrated by about 12 volumetric in-line flowmeters installed at selected sites. Using the data collected at these sites, the relation between pumpage and irrigated acreage is expected to be established statistically. With this relation and on the basis of mapped irrigated acreage, it will be possible to estimate more accurately the 1974 to 1983 pumpage for the two test areas.

Change in ground-water storage will be determined from water-level records and from the maps of estimated specific yield. The difference between pumpage and the change in ground-water storage will be used to estimate the rates of irrigation return flow. With more accurate estimates of pumpage and rates of return-flow recharge from irrigation, the flow models that were constructed during the initial Regional Aquifer System Analysis study will yield better results in understanding the flow system, as well as the effects of irrigation development. These models will then provide a useful means of evaluating potential aquifer depletion and recharge in the future.


106°
104°
102°
100°
98°
96°
42°
40°
38°
36°
34°
32°
WYOMING
SOUTH DAKOTA
NEBRASKA
PERKINS COUNTY
CHASE COUNTY
DUNDY COUNTY
COLORADO
KANSAS
OKLAHOMA
NEW MEXICO
PARMER COUNTY
CASTRO COUNTY
TEXAS
EXPLANATION
High Plains aquifer
Pumpage sampling area (1983)
0
50
100
150 MILES

High Plains aquifer. Two areas, one in the southern High Plains of Texas and the other in the northern High Plains of Nebraska, were selected for the Regional Aquifer Systems Analysis Phase II studies.

NATIONAL WATER SUMMARY PROGRAM

The U.S. Geological Survey has established the National Water Summary Program in response to recent concerns about an impending water crisis and an increased public interest in the condition of the Nation's water resources. In addition to preparing a national water summary report annually, the Program will describe the geographic extent and severity of water issues and will develop and maintain maps and statistics that describe the condition of water resources in the context of specific issues.

In January 1984, the Survey published *National Water Summary 1983—Hydrologic Events and Issues*, Water-Supply Paper 2250, the first in the planned series of reports to discuss changes and trends in the availability, quantity, quality, and use of the Nation's water resources. These reports have been designed to organize and present water information to aid in the analysis and development of water policies, legislation, and management actions by the Congress and Federal and State officials and to increase public understanding of water resources.

National Water Summary 1983 consists of four parts: A discussion of the hydrologic cycle and how man influences the movement and quality of water as it moves through the cycle; a review of recent hydrologic conditions—precipitation, streamflow, flooding, and droughts—from January 1982 through August 1983; a hydrologic interpretation of four categories of water issues—water availability, water quality, hydrologic hazards and land use, and institutional and management issues; and a State-by-State discussion of water issues in each of the four categories, highlighted by color-coded maps that show the location and extent of the issues.

A number of water issues that have nationwide significance emerged from the State summary section:

- Short-term vulnerability to drought of surface-water supplies and shallow ground-water supplies;
- Concerns about the reliability of water supplies as competition for water increases;
- Declining ground-water levels associated with increased use of ground water;
- Need for improved control of surface-water pollution, especially nonpoint sources of pollution, such as runoff from agricultural and urban areas;
- Prevention of ground-water contamination and the mitigation of existing sources of pollution, such as hazardous waste sites;
- Potential effects of acidic precipitation;
- Chronic problems of flooding;
- Effects of resource development, especially coal mining and low-head hydropower, on water resources; and
- Development of water allocation and reallocation procedures.

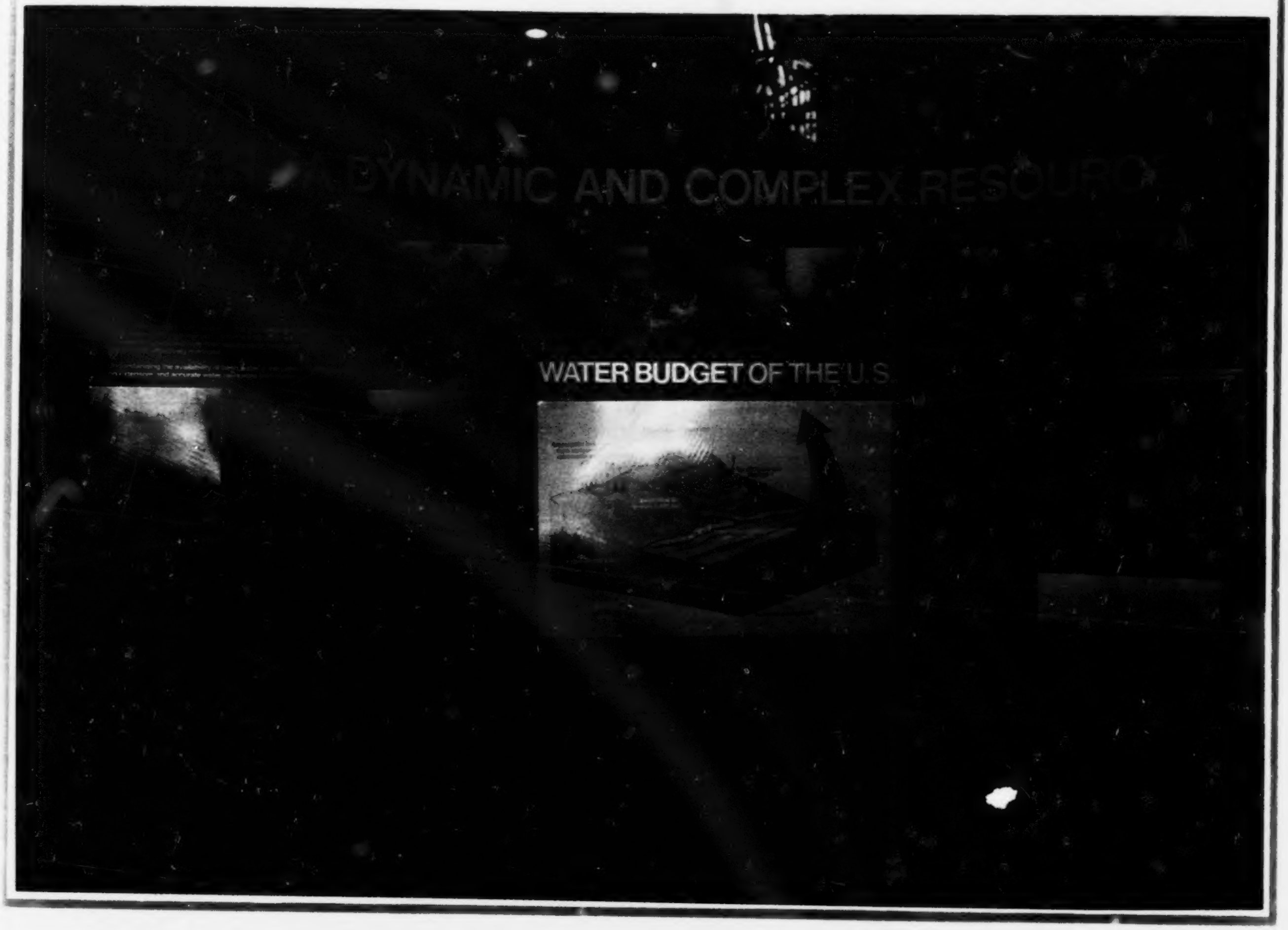
More than 8,000 copies of *National Water Summary 1983* have been distributed to Federal, State, and local agencies, the Congress, the Water Resources Research Institutes, and other members of the water-resources community. News coverage of the *Summary* was nationwide, and reviews appeared in local, State, and national newspapers and newsletters and on national network television. The favorable response to the report was due, in part, to the State-by-State presentations that one newspaper referred to as "an unprecedented State-by-State assessment of U.S. water supplies." The *National Water Summary* also was displayed prominantly as part of the Geological Survey's exhibit at the Louisiana World Exposition.

WATER RESOURCES EXHIBIT AT THE WORLD'S FAIR

The theme of the Louisiana World Exposition in New Orleans, *The World of Rivers: Fresh Water as a Source of Life*, presented an opportunity for the U.S. Geological Survey to demonstrate the importance of current streamflow data to present and potential national water-resources issues. Highlights of the Water Resources Division exhibit, "Measuring U.S. Water Resources," on display in the Great Hall of the Convention Center May 12 through November 11, 1984, were

- A display of satellite telemetry that demonstrated the latest electronic technology in making current hydrologic data available to users; visitors to the exhibit could select current and historical streamflow data and obtain a computer-graphics streamflow display of one representative stream in each State;
- A hands-on slide presentation for water use in each State;
- Panels that described why the Geological Survey collects water information, how the information is collected, and how it is used to define and manage water-resources problems. These panels also featured the *National Water Summary 1983*; and
- Panels that showed water issues of the 1980's and provided information on ground-water mining, floods, and acid precipitation.

One of the exhibit panels on water information exhibited at the World's Fair in New Orleans, Louisiana. (Photograph by John E. Moore, Water Resources Division, U.S. Geological Survey.)



International Activities

MISSION

The U.S. Geological Survey has conducted international activities as an extension of its domestic programs since about 1940. Authority for Survey participation in foreign studies derives from the revised Geological Survey Organic Act, the Foreign Assistance Act, and related legislation. Principal objectives of the activities are

- To help achieve domestic research objectives through the comparative study of scientific phenomena abroad and in the United States;
- To obtain information about existing and potential foreign resources of interest to the United States;
- To develop and maintain relations with counterpart institutions and programs which will facilitate scientific cooperation and exchange; and
- To provide support for the international programs of other Federal agencies including those of the U.S. Department of State that contribute to foreign policy objectives.

MAJOR PROGRAMS AND ACTIVITIES

International programs of the U.S. Geological Survey are usually of two general types. The first is technical assistance to other countries and international organizations utilizing funds from other Federal agencies, from international organizations, or from foreign governments as authorized under the Foreign Assistance Act and related legislation. The second is bilateral or multilateral scientific cooperation with foreign counterpart organizations under Government-approved cooperative agreements to achieve common research objectives utilizing funds appropriated for Survey research and funds or other financial resources made available by the cooperating countries or organizations.

Many related activities that form integral parts of the programs commonly stem from the international work; for example, institutional development, exchange of scientists, training of foreign nationals, and representation of the Survey or the U.S. Government in international organizations, commissions, or associations.

During fiscal year 1984, the Geological Survey continued its formal training courses for foreign nationals.

Course title	Number of attendees
22nd International Remote Sensing Workshop	10
23rd International Remote Sensing Workshop	7
Techniques of Hydrologic Investigations	24
Geologic and Hydrologic Hazards Course	42

In addition to the scheduled training courses, the Survey provided or arranged for on-the-job or academic training for 167 people either at Survey facilities or at other organizations on behalf of the Survey. The 250 trainees (including those in the formal courses) represented 55 countries; 66 trainees were from the Kingdom of Saudi Arabia. The Survey also continued to arrange programs for visiting scientists. Through these programs, 106 scientists from 25 countries conducted cooperative research at the Survey or Survey-selected institutions; 25 scientists were from the People's Republic of China.

Programs active during fiscal year 1984 are summarized in the accompanying table. The more significant highlights of fiscal year 1984 are described below.

Caribbean-South America

During 1984, the Survey developed a program supportive of the President's Caribbean Basin Initiative. The program proposes cooperative scientific research with counterpart agencies in Caribbean nations that will enhance the economic conditions and improve the health and safety of the people. The proposals are largely extensions of domestic studies such as the Strategic and Critical Minerals Program, the Geologic Frame-

International scientific activities conducted by the U.S. Geological Survey in fiscal year 1984, listed by country or region

Technical Assistance Activities	
Bangladesh	Training of Geological Survey personnel.
Colombia	Stream-flow modeling related to dam operations.
Costa Rica	Coal-resources assessment.
Dominican Republic	Reconnaissance of Jayaco concession.
Egypt	Technology transfer and personnel training; remote sensing.
El Salvador	Earthquake hazards reduction.
Guatemala	Do.
Guinea	Earthquake damage assessment and mitigation.
Indonesia	Volcanic research and hazards mitigation; peat-resource consultancy.
Jordan	Seismic systems; ground-water resources; geothermal resources.
Kenya	Regional remote sensing facility; Landsat imagery.
Kingdom of Saudi Arabia	Geologic mapping and mineral-resource assessment; hydrologic studies; Landsat image quadrangle maps.
Latin America	Earthquake disaster mitigation in Andean region.
Madagascar	Mineral-resource project development.
Morocco	Landsat image base map compilation.
Panama	Earthquake hazards reduction.
Paraguay	Hydrologic hazards related to floods.
Peru	Mineral-resources assessment; flood hazards in Cuzco.
Philippines	Geoscience map publication assistance.
Portugal	Geothermal resources; seismic hazards, San Miguel Island, Azores.
Senegal	Hydrogeology of Senegal River alluvium related to dam construction.
Southeast Asia	Earthquake engineering and hazards mitigation; engineering seismology.
Thailand	Lignite research; map publication assistance; mineral deposit and natural gas symposia.
Tunisia	Remote sensing; Landsat image mosaic map production.
Venezuela	Hydrology and water resources of Orinoco Basin.
Worldwide	Global seismic network; geologic and hydrologic training programs; conventional energy-resources identifications.

Scientific Cooperative Activities	
Antarctica	Topographic mapping; marine geological and geophysical surveys.
Bolivia	Subvolcanic intrusions related to ash-flow tuff terranes and tin resources.
Brazil	Magnetotelluric surveys; river sediment studies.
Canada	Strategic minerals inventory; seafloor mineral exploration; borehole geophysics; continental deep seismic reflection.
Chile	Volcano studies.
Colombia	Mineral-resources assessment; geochemical exploration.
Costa Rica	Geothermal-energy consultation; magnetic observatory instrumentation.
Dominican Republic	Offshore shelf studies.
France	Marine hydrothermal mineralogy; geophysics.
Germany	Strategic minerals inventory; marine seismic studies of continental margins; radioactive waste; petroleum-resource assessment; Antarctic research.
Greece	Geochemistry of petroleum.
Hungary	Seismic stratigraphy, reflection seismic, electromagnetic, mineralogic, paleomagnetic and paleoenvironmental studies.

International scientific activities conducted by the U.S. Geological Survey in fiscal year 1984, listed by country or region –Continued

	Scientific Cooperative Activities
Iceland	Volcano and geothermal studies.
Italy	Seismology and seismic risk assessment; geochemistry; volcanology; marine geology.
Japan	Joint panels on earthquake prediction, marine geology, marine mining; symposium on resources of 1990's; massive sulfide assessments.
Mexico	Volcano studies; geochemical and geophysical exploration; mineral and metallogenic map analyses; regional structure and stratigraphic studies; tectonostratigraphic terrane studies.
Nepal	Geologic and hydrologic training and resource assessments.
Pacific region	South Pacific cruise; hydrocarbon-resources studies; oceanic crusts studies; chromite resources; Circum-Pacific mapping.
People's Republic of China	Earthquake studies; remote sensing; volcanism and metallogeny; coal basin studies; petroleum geology of carbonate rocks; Circum-Pacific geologic and tectonic framework; surface-water hydrology.
South Africa	Strategic minerals inventory.
South Korea	Offshore petroleum-resources and geothermal-resources assessments.
Southeast–East Asia	Seafloor geologic mapping; petroleum geology research; sedimentary basin analysis.
Spain	Ground-water resources; remote sensing for mineral deposits; earthquake research; marine geology of continental margins.
Sweden	Nuclear waste disposal.
United Kingdom	Marine geology; world coal resources.
U.S.S.R	Joint committee on earthquake prediction.
Yugoslavia	Crustal structure research; seismology and earthquake hazards; subsidence research; geochemical surveys; remote sensing; engineering geology; geophysics.
Worldwide	International Strategic Mineral Inventory; World Energy Resources Program.

work Program, and the Earthquake Hazards Reduction Program. As an initial contribution to the Carribean program, the Geological Survey published Circular 925, *Earth and Water Resources and Hazards in Central America*, which is a review of information available for natural resources in the region and the potential impact of geologic hazards such as earthquakes, landslides, and volcanic eruptions. Survey scientists have briefed officials of the Department of the Interior, the Department of State, and the U.S. Agency for International Development throughout the year to acquaint them with the resource and hazards potential of the region and to outline the Survey's proposals for study.

The Caribbean nations have onshore, and possibly offshore, deposits of gold, silver, and, to a lesser extent, platinum. Coal and rock phosphate deposits are known but unassessed. Potential areas for oil and gas development are untested for the most part. Geothermal energy resources are developed locally, but their potential for development elsewhere is just now being considered. Development of reliable potable water supplies and their protection from pollution are of considerable interest in the Caribbean nations, and mitigation of the risks from geologic hazards is necessary to the safety and well-being of the inhabitants. As initial activities in the Caribbean basin, the Geological Survey proposes onshore and offshore energy- and mineral-resource studies, geologic and hydrologic surveys, and geologic hazards studies. Programs of regional geological mapping using sophisticated geophysical and geochemical techniques are needed to assess the potential of the area.

Phosphate Symposium

The Survey, East Carolina University, and the International Geological Correlation Program (IGCP) Project 156 sponsored a workshop on the potential for discovery of useful phosphate deposits in the Caribbean. The workshop was held at East Carolina University, Greenville, North Carolina, in July 1984. Scientists from Colombia, the Dominican Republic, Costa Rica, Honduras, Jamaica, Guatemala, Venezuela, and Mexico met with U.S. specialists to consider the regional and detailed geologic studies needed to assess the rock phosphate potential that would provide an accessible local source of agricultural fertilizer. The development of this resource will be a giant step towards mitigating the region's severe food production problems. As a result of the workshop, the country representatives now are working to establish a Caribbean basin phosphate resources group to plan and coordinate phosphate assessment in the region. The U.S. Geological Survey and the IGCP Project 156 will provide advice and assistance to this regional resource group.

Costa Rica

In July 1983, the Survey initiated a technical assistance program in coal-resources assessment and exploration with Costa Rican counterparts in the Gerencia de Exploración de Refinadora Costarricense de Petroleo (RECOPE) under the auspices of the Agency for International Development. A RECOPE geologist received on-the-job training in coal exploratory and drillhole geophysical logging techniques with Geological Survey counterparts in the Powder River Basin of Wyoming during that summer. In 1984, three of nine coal-bearing areas in Costa Rica were targeted for study; in the Volio area in the southeast, RECOPE is drilling to determine the quantity of coal available; reconnaissance mapping and surface exploration are being done in the Venado area to the north and in the Zent area to the east. Survey personnel advise and train RECOPE counterparts in coal mapping and resource assessment methodologies, exploratory drilling and downhole geophysical logging techniques, and coal sample collection, processing, and analysis. Assessment of the quality of Costa Rican coal will be accelerated with completion of a Survey-designed coal analytical laboratory in RECOPE under the leadership of a Costa Rican chemist who received training this year at a Survey-selected commercial laboratory in the United States. Development of coal resources of the Caribbean region for utilization in the production of electricity will decrease the dependency on imported oil. As a source to replace fuelwood, coal utilization can alleviate severe problems caused by deforestation in the region.

Colombia

A geologic synthesis and mineral resource assessment of Colombia was completed in 1984 with cooperation of scientists from the Survey and the Instituto de Investigaciones Geologico-Mineras in Colombia. This project was designed to organize and review existing geologic information to identify terranes in Colombia that have the greatest potential for new mineral discoveries. Mineral deposit models were developed and adapted for deposits that occur in Colombia or in similar terranes elsewhere, and guides for further mineral resource studies and assessments were presented. The cooperative review provides a solid base for the planning of more detailed programs of exploration in South and Central America and Caribbean nations. Concurrent and follow-up cooperative studies thus far undertaken include assistance in the establishment of a microcomputer-based geochemical data base, workshops and assistance in the conduct of geochemical surveys and chemical analyses, planning of cooperative marine mineral research, seminars for a national rock phosphate assessment program, and research for a national geologic hazards reduction program. Results of the assessment have been released as U.S. Geological Survey

Open-file Report 84–345 titled *Mineral Resource Assessment of Colombia.*

The Geological Survey and the Corporacion Autónoma Regional del Cauca, a Colombian organization similar to the Tennessee Valley Authority, are cooperating in a project to simulate by mathematical model the streamflow of the Cauca River in northwestern Colombia. Colombian scientists will evaluate the applicability of a Survey-developed model to the Cauca River to guide the operation of a dam which will become functional in early 1985. Satellite data relay also will be used with the model to obtain realtime data on river stages and meteorologic conditions for realtime operation of the model.

Peru

Technical assistance and institutional development continued in 1984 in Peru where Survey scientists trained and guided geologists and geochemists of the Empresa Minera del Centro del Perú in geological and geochemical mapping and in sample processing and analyses at a Survey-designed laboratory. Investigations continued in the Puquio prospect and began in the Acos concession, which are in the Sur Medio region. Frequency distribution tables, single and multielement distribution maps, preliminary geologic maps, and accompanying reports are in preparation.

South Pacific–East Asia

The U.S. Geological Survey's Research Vessel *Samuel P. Lee* completed a 3-month, 4-leg resource appraisal cruise in the southwest Pacific in 1984 as part of "Operation Deep Sweep," a pole-to-pole expedition designed to obtain data to further the knowledge of tectonic processes and resource potential of the Pacific Basin. The scientific expedition, the second in as many years, is a continuation of the Australia-New Zealand-United States (ANZUS) Tripartite Geoscientific Resource Investigation in the southwest Pacific under the direction of the Committee for Coordination of Joint Prospecting for Mineral Resources in South Pacific Offshore Areas (CCOP/SOPAC). The expedition took the ship from San Francisco to the Bering Sea and Hawaii, from there to international waters offshore of the nations of Kiribati, Samoa, New Zealand, Antarctica, Fiji, Tonga, Vanuatu, and Papua New Guinea, and returning to San Francisco via the Marshall Islands and Hawaii. Results of the Antarctica portion of the cruise are described in the article titled *The Antarctic Leg of "Operation Deep Sweep"* in the Geologic Investigations chapter.

The recently completed ANZUS–CCOP/SOPAC investigation was successful in delineating structural and stratigraphic features that may be promising mineral- or energy-resource targets. In the Tonga-Lau region, a shallow magma chamber was identified that could possibly be a source for polymetallic mineralization. In Vanuatu, the Torres–Santa Cruz basin was found to be quite extensive (over 7,000 square miles) and to contain sediment about 3 miles thick. The sedimentary basins associated with the Central Solomons Trough and offshore New Ireland basin in eastern Papua New Guinea were defined further and found to contain structures that could trap oil and gas.

The Geological Survey conducted a 6-month pilot study to analyze Tertiary sedimentary basins in the Circum-Borneo offshore areas of Malaysian Sarawak and Sabah, Brunei, Indonesian Kalimantan, and the southwestern Philippines as a forerunner to a planned program in basin analysis of the East Asia Region (fig. 1). The study was undertaken as part of a proposed cooperative program for the evaluation of sedimentary basins for the International Union of Geological Sciences and was carried out in cooperation with the United Nations Coordinating Committee for Joint Prospecting of Mineral Resources in Asian Offshore Areas. The objective of the pilot study was to demonstrate methodologies and to assist the nations involved in an assessment of the petroleum resources of the region. The analysis was done within the extended framework of the Circum-Pacific Map Project in that data was supplied by the countries involved,

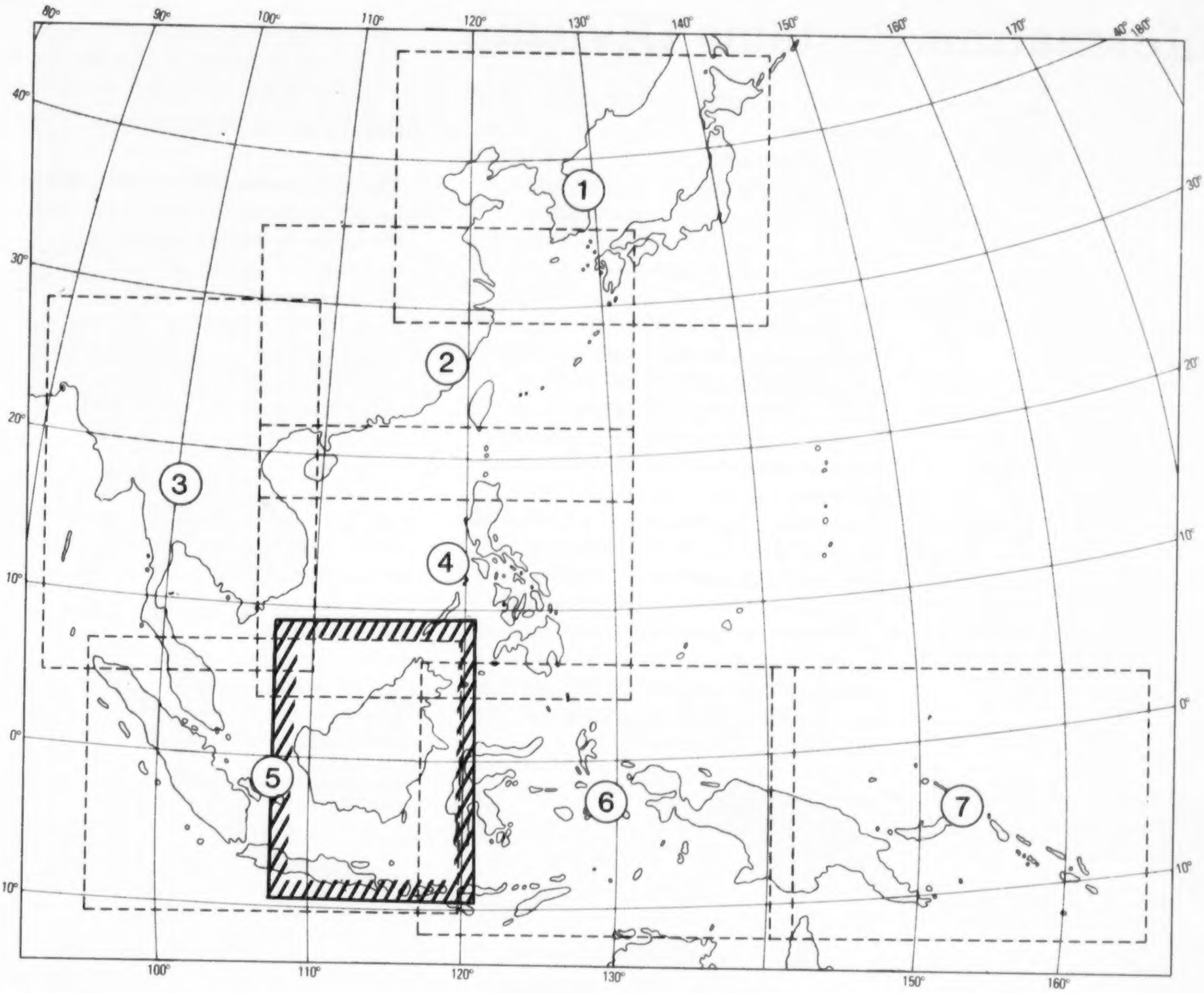


Figure 1. *Index of maps for the East Asia basin-analysis program showing the Circum-Borneo pilot study area (hachured).*

and base map cartography, compilation of data, and coordination of the program were done by the U.S. Geological Survey.

Many governmental agencies and private companies throughout East Asia supplied useful data, particularly for the offshore and subsurface in the Circum-Borneo pilot study area. The Geological Survey is synthesizing the data into a series of maps at a scale of 1:2 million: (1) a Tertiary basin outline map, (2) a Tertiary sediment thickness and structure map (depth to economic basement), (3) a Paleogene sediment isopach map, (4) a Paleogene paleogeographic and paleoenvironmental map, (5) a Neogene sediment isopach map, and (6) a Neogene paleogeographic and paleoenvironmental map. Representative stratigraphic columnar sections and cross sections for all basins also are being prepared. The data will be released in preliminary form as a Survey open-file report before editing and processing as a formal publication.

Information Systems Division

MISSION

The Information Systems Division provides support and advice to the Director of the U.S. Geological Survey, the Department of the Interior, other government agencies, and the other Divisions of the Survey on all matters relating to Bureau information technology and automated data processing (ADP) services. It provides these services along with acquisition assistance for users of large general-purpose computers, smaller special purpose computers, and telecommunications. The Division provides for coordination and growth of information systems through systems analysis and design and conducts ADP research into better ways to use technology to solve mission-related problems. It is responsible for guidelines for data standards, data administration, and data base management.

BUDGET AND PERSONNEL

The Information Systems Division had a budget of $20 million for fiscal year 1984. Other Survey Divisions and Department of the Interior and Federal agency users provided funding.

As a Department of the Interior General Purpose Computer Center, the Division computing facilities were available to other Interior offices and bureaus as well as to all Survey Divisions.

Division staffing consisted of 167 full-time employees, primarily computer specialists, computer analysts, mathematicians, systems programmers, computer scientists, and technicians. The staff was augmented by part-time and intermittent employees and contract personnel who greatly assisted in fulfilling the mission of the Division. These employees served customers from the five ADP

At one of the demonstration booths set up in the center, a SuperBrain equipped with a Maxtex XCEL graphics board displays a design. The SuperBrain also has software to drive the Bausch & Lomb DMP–29 plotter.

Service Center sites nationwide: National Center, Reston, Virginia, Washington, D.C., Menlo Park, California, Denver, Colorado, and Flagstaff, Arizona.

ACCOMPLISHMENTS

Opening of Technology Information Centers

During fiscal year 1984, the Information Systems Division opened technology information centers at the National Center and the Flagstaff and Denver service center sites. The centers primarily emphasize small computer technology; however, plans are underway to demonstrate how small and large computer technologies can be integrated.

The Centers provide the following capabilities:

- Demonstrations by in-house personnel and vendors showing the use of specific small computers and associated software packages;
- A library containing a variety of publications related to computing technology;
- A clearinghouse for distributing information about vendors, equipment, user groups, software, and data bases developed for or accessible with computers in the Survey;
- Consultations on equipment, software, and computer acquisition; and
- Individual instruction using computer-assisted instruction and videotapes.

During fiscal year 1984, the centers were visited by over 3,000 Survey employees: Scientists who had a need to find out how small computer technology can help in supporting their programs, managers who had a need to find out how technology can help them to make decisions and produce reports, administrators who were considering new systems to enhance office productivity or who wanted to understand more about the capabilities of those that they are using, and ADP professionals who were interested in keeping up with technology.

LASER OPTICAL DISK TECHNOLOGY

The Survey is continuing a program to improve digital mass storage capability and to provide facilities for increasing amounts of digital scientific data. This year, the Survey and a private corporation will be testing the first production model of a new laser optical disk storage system that will provide more cost-effective, easily accessible, digital data storage for scientific data bases as well as digitized images of graphs, maps, reports, and administrative records. Test applications and pilot projects are being developed with the operating divisions to evaluate the utility of this new technology. The new method will increase capacity 10 times over that of magnetic storage, with costs per character similar to that of microfiche. The National Mapping Division will test the device for storage of the Digital Cartographic Data Base, and the Information Systems Division will examine its use for various geologic and hydrologic data, streamflow graphs, text of scientific papers, and administrative records.

ACQUISITION ASSISTANCE

Division assistance for acquiring information technology services continued during 1984. The assistance included requirements definition, documentation preparation, regulatory approvals acquisition, technical evaluation of proposed computer resources, contract administration functions, and management of the Bureau computer resource reutilization program.

An automated acquisition tracking system was designed and implemented to provide a more effective method of process control, thereby enhancing the computer resource acquisition process. Over 3,500 requests for various automation products and services with expenditures exceeding $50 million were processed this fiscal year.

The Division provided acquisition assistance for the Water Resources Distributed Information System, Earthquake Studies Program, Digitized Mapping Information, Marine Geology Research Program, Public Inquiries

System, and the modernization of the General Purpose Computer Centers. Additional efforts include office automation projects, administrative support functions, and acquisition of the nationwide voice and data communications networks.

EARTH SCIENCE INFORMATION ACCESS AND DELIVERY

During the past year, access to and delivery of earth science information was substantially improved by the use of the Earth Science Information Network at the National Cartographic Information Centers and the Public Inquiries Office of the Survey. The Information Systems Council is developing plans for extending the network and using it at other Survey offices to further improve the dissemination of earth science information. These changes will make products and data resulting from Survey research and investigations more readily available to inquirers.

Visitors can select from a variety of videocassette tapes to satisfy their microcomputer training needs.

Establishment of the Earth Science Information Center (ESIC) is scheduled to more conveniently provide needed technical assistance in analyzing, evaluating, and interpreting the products and data that are, in part, obtained by referral from the information network. The ESIC will be located in the Main Interior Building in Washington, D.C., and the capabilities of its professional staff, drawn from each of the program divisions, will help the scientific community in the Federal Government to use the results of Survey earth science activities. The staff will have available a full range of computerized reference tools and instrumentation.

ARTIFICIAL INTELLIGENCE TECHNIQUES APPLIED TO EARTH SCIENCE INFORMATION

The Survey is exploring the use of artificial intelligence concepts as they relate to earth science data bases. One approach uses systems that require teaching the computer to accept a set of

This demonstration booth displays two offerings in the IBM personel computer product line, the IBM PC (left) and the IBM PC/XT (right).

rules. These rules then are coupled with facts in a data base to provide solutions to problems. While the program is being used, more rules can be added by the user. This program will be of value in dealing concurrently with many data sets and should result in the development of new knowledge that will be retained and reported back to the researcher. Although artificial intelligence can be used in many areas, the Survey's initial work is on the subject of geographic information. In the project, Knowledge-Based Geographic Information Systems, a new form of data structure for spatial data was designed. Software has been developed to demonstrate the system, and new techniques for searching earth science and geographic data bases will result.

FISCAL YEAR 1984 INFORMATION SYSTEMS COUNCIL ACTIVITIES

The Information Systems Council, chaired by the Assistant Director for Information Systems and including policy-level representatives from the Divisions and regions, focuses on developing ADP technical policy and coordinating ADP technology within the Survey and with the Department of the Interior. In the policy area, the Council developed a chapter on Systems Life Cycle Management for inclusion in the Geological Survey Manual. The purpose of the chapter is to establish a policy for systematically managing the activities and phases during the life span of an information system. Serving in its coordination role, the Council reviewed the minicomputer procurement for the National Mapping Division's digital line graph processors and developed ideas for a policy to promote hardware and software resource sharing within the Survey.

Increased capabilities as a result of technological advances continue to offer opportunites for the Survey to distribute small computers to its many field locations. Consequently, communications are becoming a critical factor in ensuring access to these distributed computers and in facilitating sharing of data and software among them. In recognition of the essential nature of these communications, the Information Systems Council undertook two actions this year. The first was a Bureauwide evaluation of the Survey's current data and voice communications activities and an analysis of alternative future strategies. The second was the formation of the Bureau-level Telecommunications Utility Commission. The Commission, which reports to the Council, serves as a forum to ensure that Divisions are focusing management attention on their telecommunications requirements. The Commission will review major communications acquisitions and changes and will work to equitably allocate telecommunications costs. Additionally, the Commission will review major policy issues requiring resolution by the Council.

The Information Systems Council is committed to making earth science information more accessible and used more effectively. An increasingly important challenge in scientific studies is to be able to integrate diverse earth science data sets. To this end, the Council has initiated a bureauwide project to develop a standardized system which will allow researchers and casual users to integrate and display data bases in a consistent structure.

Digital Private Automatic Branch Exchange

The Division participated in the acquisition of the digital Private Automatic Branch Exchange, the new telephone systems for Reston and Menlo Park. The systems will provide extensive support to data and state-of-the-art voice communications capabilities.

Communications Network Services

A Request for Proposals to acquire the use of a nationwide computer network was prepared for release. The network will permit connection of Survey computers as host computing resources and will provide access to these resources for all local and remote location users. The network is expandable and will permit new technology to be installed and used throughout the life of the contract. This service will replace many fragmented communications facilities and will result in a unified approach to computer communications within the Survey. During the term of the contract, this network will provide opportunities to integrate voice and data over common communications lines resulting in significant opportunities to reduce expenses.

Telecommunications Task Force

Due to the increasing complexity of telecommunications (which includes data and voice communications) as a result of industry deregulation, the Division consolidated its resources to permit more careful coordination of essential telecommunications functions. The primary objectives of this action were the completion of the Communications Network Services, the culmination of the digital Private Automatic Branch Exchange acquisition, the move of the communications facilities coincident to the relocation of the computer systems at the National Center, and the planning, coordinating, and operating of all Survey telecommunications facilities nationwide.

Small Computer Accomplishments

Major accomplishments included the completion of the Event Alert System, the Budget Information Management System, and a multiuser system for automating actions pertaining to employee training.

The purpose of the Event Alert System is to notify key officials of the Survey of naturally occurring hazards; that is, seismic or volcanic activity. This

In the center's library, users can read articles in the latest computer periodicals or consult one of several catalogs describing software packages.

notification is accomplished from geographically separate offices of the Office of Earthquakes, Volcanoes, and Engineering of the Geologic Division. A small computer in Reston receives the information and automatically forwards it to other small computers in the homes of key personnel.

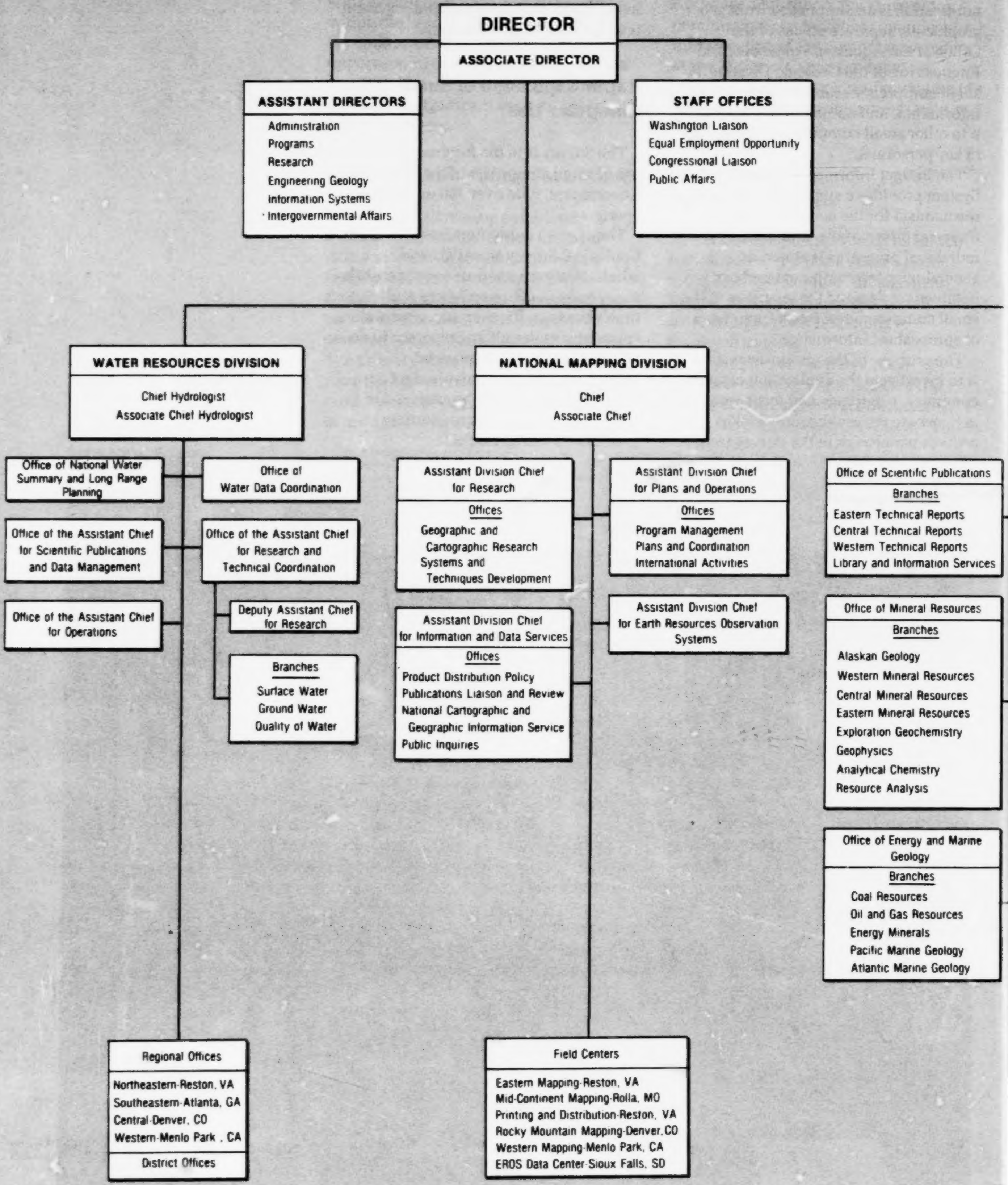
The Budget Information Management System provides a similar reporting mechanism for the accrual of Survey financial information. Information on individual programs is stored on general-purpose computers and can be obtained on demand for inclusion at the small computer level into a framework of spreadsheet information.

The purpose of the multiuser system is to investigate the application of small computer technology and local area networks to reduce the time it takes to process paperwork in the Survey training office. A multiuser computer system is in the final stages of testing.

Rapid Expansion of Small Computer Use

The Survey is in the forefront in the use of small computers in the Federal Government, with over 700 units now operating.

These small computers have enabled Geological Survey scientists and administrative personnel to accomplish many tasks in a more efficient and timely manner; for example, electronic spreadsheets permit an employee to do "what if" analysis on financial information, and, because budget allocation can quickly be analyzed in a total context, much more accurate predictions can be made.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Engineering Geology
Information Systems
Intergovernmental Affairs
STAFF OFFICES
Washington Liaison
Equal Employment Opportunity
Congressional Liaison
Public Affairs
WATER RESOURCES DIVISION
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Associate Chief Hydrologist
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Office of Water Data Coordination
Office of the Assistant Chief for Scientific Publications and Data Management
Office of the Assistant Chief for Research and Technical Coordination
Office of the Assistant Chief for Operations
Deputy Assistant Chief for Research
Branches
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Ground Water
Quality of Water
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Southeastern-Atlanta, GA
Central-Denver, CO
Western-Menlo Park, CA
District Offices
NATIONAL MAPPING DIVISION
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Associate Chief
Assistant Division Chief for Research
Offices
Geographic and Cartographic Research
Systems and Techniques Development
Assistant Division Chief for Plans and Operations
Offices
Program Management
Plans and Coordination
International Activities
Assistant Division Chief for Information and Data Services
Offices
Product Distribution Policy
Publications Liaison and Review
National Cartographic and Geographic Information Service
Public Inquiries
Assistant Division Chief for Earth Resources Observation Systems
Field Centers
Eastern Mapping-Reston, VA
Mid-Continent Mapping-Rolla, MO
Printing and Distribution-Reston, VA
Rocky Mountain Mapping-Denver, CO
Western Mapping-Menlo Park, CA
EROS Data Center-Sioux Falls, SD
Office of Scientific Publications
Branches
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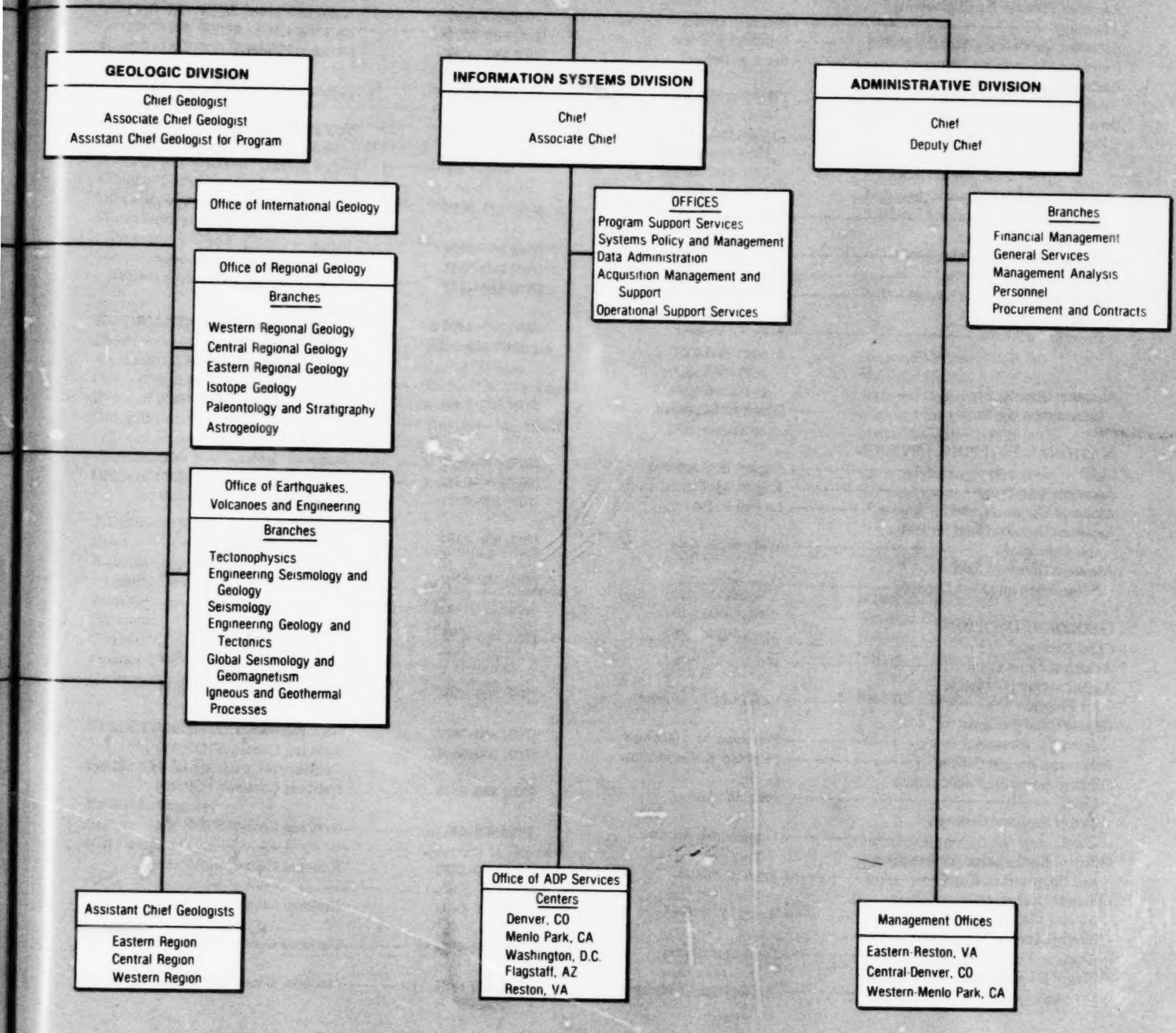
Geophysics
Analytical Chemistry
Resource Analysis
Office of Energy and Marine Geology
Branches
Coal Resources
Oil and Gas Resources
Energy Minerals
Pacific Marine Geology
Atlantic Marine Geology

Organizational and Statistical Data

ORGANIZATION OF THE GEOLOGICAL SURVEY

U.S. Department of the Interior


GEOLOGIC DIVISION
Chief Geologist
Associate Chief Geologist
Assistant Chief Geologist for Program
Office of International Geology
Office of Regional Geology
Branches
Western Regional Geology
Central Regional Geology
Eastern Regional Geology
Isotope Geology
Paleontology and Stratigraphy
Astrogeology
Office of Earthquakes, Volcanoes and Engineering
Branches
Tectonophysics
Engineering Seismology and Geology
Seismology
Engineering Geology and Tectonics
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Eastern Distribution Branch
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Alaska Distribution Section
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Reston, VA 22092

To subscribe to the *Earthquake Information Bulletin*, write:
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Government Printing Office
Washington, DC 20402

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Anchorage, AK 99501

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Anchorage, AK 99513
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300 N. Los Angeles St.
Los Angeles, CA 99012

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Menlo Park, CA 94025
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12201 Sunrise Valley Dr.
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421 National Center
12201 Sunrise Valley Dr.
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Office of Water Data Coordination
417 National Center
12201 Sunrise Valley Dr.
Reston, VA 22092

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Hydrologic Information Unit
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Arkansas Department of Pollution Control and Ecology (w); Arkansas Soil and Water Conservation Commission (w); Arkansas Geological Commission (g,n,w); Arkansas State Highway and Transportation Department (w); Arkansas Department of Parks and Tourism (w)

California:

Alameda County—Flood Control and Water Conservation District (Hayward) (w), Flood Control and Water Conservation District, Zone 7 (Livermore) (w), Water District (w); Antelope Valley–East Kern Water Agency (w); California Department of—Boating and Waterways (w), Fish and Game (Sacramento) (w), Fish and Game, Region II (Rancho Cordova) (w), Health Services (w), Transportation, District 3 (Marysville); (w), Water Resources—Central District (Sacramento) (w), Northern District (Red Bluff) (w), San Joaquin District (Fresno) (w); California Regional Water Quality Control Board—Central Coast Region (San Luis Obispo) (w), Colorado River Basin Region (Palm Desert) (w), North Coast Region (Santa Rosa) (w), San Francisco Bay Region (Oakland) (w), Santa Ana Region (Riverside); (w); California Water Resources Control Board (w); Carpointeria County, Water District (w); Casitas Municipal Water District (w); Coachella Valley, County Water District (w); Contra Costa County—Department of Health Services (w), Flood Control and Water Conservation District (w); Crestline-Lake Arrowhead Water Agency (w); Desert Water Agency (w); East Bay Municipal Utility District (w); East San Bernardino County Water District (w); El Dorado County (w); Fresno County, Department of Resources and Development (w); Fresno Metropolitan Flood Control District (w); Georgetown Divide Public Utility District (w); Goleta County Water District (w); Humboldt Bay, Municipal Water District (w); Imperial County, Department of Public Works (w); Imperial Irrigation District (w); Indian Planning Consortium–Central California (w); Indian Wells Valley Water District (w); Inyo County Water Department (w); Kern County Water Agency (w); Kings River Conservation District (w); Lake County, Planning Department (w); Los Angeles County, Flood Control District (w); Los Angeles Department of Water and Power (w); Madera County, Flood Control and Water Conservation Agency (w); Madera Irrigation District (w); Marin County, Department of Public Works (w); Marin Municipal Water District (w); Merced, City of (w); Merced Irrigation District (w); Modesto, City of, Department of Public Works (w); Modoc County, Department of Public Works (w); Mojave Water Agency (w); Montecito County Water District (w); Monterey County Flood Control and Water Conservation District (w); Monterey Peninsula, Water Management District (w); Napa County Flood Control and Water Conservation District (w); Newport Beach, City of (w); Orange County— Environmental Management Agency (w), Water District (w); Oroville–Wyandotte Irrigation District (w); Pacheo Pass Water District (w); Paradise Irrigation District (w); Placer County Water Agency (Auburn) (w); Placer County Water Agency (Foresthill) (w); Rancho California Water District (w); Riverside County Flood Control and Water Conservation District (w); Sacramento Regional County Sanitation District, Department of Public Works (w); San Benito County Water Conservation and Flood Control District (w); San Bernardino Valley Municipal Water District (w); San Diego, City of (w); San Diego County, Department of—Planning and Land Use (w), Public Works (w); San Diego County Water Authority (w); San Francisco, City and County of, Hetch Hetchy Water and Power (w); San Francisco Water Department (w); San Joaquin County Flood Control and Water Conservation District (w); San Luis Obispo County, Engineering Department (w); San Mateo County—Department of Planning (w), Department of Public Works (w); Santa Barbara, City of, Department of Public Works (w); Santa Barbara County—Flood Control and Water Conservation District (w), Water Agency (w); Santa Clara Valley, Water District (w); Santa Cruz County—Flood Control and Water Conservation District (w), Planning Department (w); Santa Cruz, City of, Water Department (w); Santa Maria Valley Water Conservation District (w); Santa Rosa Band of Mission Indians (w)—Siskiyou County Flood Control and Water Conservation District (w), Sonoma County—Planning Department (w), Water Agency (w); Soquel Creek County Water District (w); Stanford University (g); Tahoe Regional Planning (w); Terra Bella Irrigation District (w); Thousand Oaks, City of (w); Tulare County, Flood Control District (w); Turlock Irrigation District (w); United Water Conservation District (w); University of California—Berkeley, Agricultural Experiment Station, Department of Forestry and Resource Management (w), Davis, Division of Environmental Studies (w); Ventura County, Public Works Agency (w); Western Municipal Water District (w); Westlands Water District (w); Woodbridge Irrigation District (w); Yolo County, Flood Control and Water Conservation District (w)

Colorado:

Arkansas River Compact Administration (w); Arvada, City of (w); Aspen, City of (w); Aurora, City of (w); Boulder, County of, Department of Public Works (w); Breckenridge, Town of (w); Central

Yuma Ground Water Management District (w); Cherokee Water and Sanitation District (w); Colorado Department of—Health (w); Natural Resources (g); Colorado Division of Mined Land Reclamation (w); Colorado Division of Water Resources, Office of the State Engineer (w); Colorado River Water Conservation District (w); Colorado Springs, City of—Department of Public Utilities (w), Office of the City Manager (w); Copper Mountain Water and Sanitation District (w); Custer, County of (w); Delta County, Board of County Commissioners (w); Denver, City and County, Board of Water Commissioners (w); Denver Regional Council of Governments (w); Eagle County, Board of Commissioners (w); El Paso County Water Users Association (w); Englewood, City of, Bi-City Wastewater Treatment Plant (w); Frenchman Ground Water Management District (w); Fruita, City of (w); Garfield County (w); Glenwood Springs, City of (w); Grand County Board of Commissioners (w); Larimer-Weld Regional Council of Governments (w); Marks Butte Ground Water Management District (w); Metropolitan Denver Sewage Disposal District No. 1 (w); Northern Colorado Water Conservancy District (w); Northwest Colorado Council of Govt. (w); Pitkin County, Board of Commissioners (w); Pueblo Civil Defense Agency (w); Purgatoire River Water Conservancy District (w); Rio Blanco County, Board of County Commissioners (w); Rio Grande Water Conservation District (w); Sand Hills Ground Water Management District (w); Southeastern Colorado Water Conservancy District (w); Southern High Plains GWMD (w); Southwestern Colorado Water Conservancy District (w); Steamboat Springs, City of (w); Trinchera Conservancy District (w); Uncompahgre Valley Water Users' Association (w); Upper Arkansas River Water Conservancy District (w); Upper Black Squirrel Creek (w); Upper Yampa Water Conservancy District (w); Urban Drainage and Flood Control District (w); Water Users No. 1 (Rangely) (w); W-Y Ground Water Management District (w); Yellow Jacket Water Conservancy District (w)

Connecticut:

Connecticut Department of Environmental Protection (g, n, w); Enfield, Town of (w); Fairfield, Town of, Conservation Commission (w); Meriden, Town of, Department of Public Works (w); New Britain, City of—Board of Water Commissioners (w), Improvement Commission (w); New Haven Water Company (w); Northeast Connecticut Regional Planning Agency (w); Norwalk, Town of (w); Ridgefield, Town of (w); Simsbury, Town of (w); Stonington, Town of (w); Torrington, City of (w)

Delaware:

Department of Natural Resources and Environmental Control (w); Geological Survey (w); New Castle County, Public Works Department (w)

District of Columbia:

Department of Environmental Services (w)

Florida:

Department of Natural Resources (n); Big Cypress Basin Board (w); Boca Raton, City of (w); Bradenton, City of (w); Brevard County, Board of County Commissioners (w); Broward County—Environmental Quality Control Board (w), Water Resources Management Division (w); Cape Coral, City of (w); Clearwater, City of (w); Collier, County of (w); Cocoa, City of (w); Coordinating Council on the Restoration of Kissimmee River Valley and Taylor Creek-Nubbins Slough Basin (w); Daytona Beach, City of (w); Englewood Water District, Board of Supervisors (w); Escambia County, Board of County Commissioners (w); Flagler County, Board of County Commissioners (w); Florida Department of—Environmental Regulation, Bureau of Water Resources Management (w), Division of Recreation and Parks (w), Natural Resources, Division of Marine Resources (w); Transportation (n,w); Florida Institute of Phosphate Research (w); Florida Keys Aqueduct Authority (w); Fort Lauderdale, City of (w); Fort Walton Beach, City of (w); Gainesville, City of (w); Hallandale, City of (w); Hernando, County of (w); Highland Beach, Town of (w); Hillsborough County (w); Hollywood, City of (w); Indian River County (w); Jacksonville, Consolidated City of—Department of Health and Environmental Services (w), Department of Public Works (w); Jacksonville Plan Department (w); Joshua Water Control District (w); Juno Beach, Town of (w); Jupiter Inlet District (w); Lake County—Board of County Commissioners (w), Pollution Control Department (w); Lee County, Board of County Commissioners (w); Leon County—Courthouse (w), Department of Public Works (w); Manatee County, Board of County Commissioners (w); Marion County, Board of County Commissioners (w); Metropolitan Dade County—Department of Environmental Resources Management (w); Miami-Dade Water and Sewer Authority (w); Northwest Florida Water Management District (w); Old Plantation Water Control District (w); Orange County, Board of County Commissioners (w); Palm Beach County, Board of County Commissioners (w); Pasco, County of (w); Perry, City of (w); Pinellas County, County Courthouse (w); Pinellas Park Water Management District (w); Polk County, Board of County Commissioners (w); Pompano Beach, City of, Water and Sewer Department (w); Quincy, City of (w); Reedy Creek Improvement District (w); Sarasota, City of (w); Sarasota, County of (w); South Florida Water Management District (w); Southwest Florida Regional Planning Council (w); Southwest Florida Water Management District (w); St. Johns, County of (w); St. Johns River Water Management District (w); St. Petersburg, City of (w); Stuart, City of (w); Sumter County, Recreation and Water Conservation and Control Authority (w); Suwannee River Authority (Live Oak) (w); Suwannee River Authority (Trenton) (w); Suwannee River Water Management District (w); Tallahassee, City of, Underground Utilities (w); Tampa, City of (w); University of South Florida (w); Walton, County of (w); West Coast Regional Waters Supply Authority (w); Winter Haven Lake Region (w); Winter Park, City of (w)

Georgia:

Albany, City of, Water, Gas, and Light Commission (w); Bibb County, Board of County Commissioners (w); Brunswick, City of (w); Chatham County, Board of County Commissioners (w); Clayton County, Water Authority (w); Consolidated Government of Columbus (w); Covington, City of (w); Georgia Department of—Natural Resources—Environmental Protection Division (w), Geological Survey (n,w); Transportation (w); Macon-Bibb County, Water and Sewage Authority (w); Valdosta, City of (w)

Guam: (See Hawaii)

Hawaii:

American Samoa, Government of (w); Guam, Government of (w); Hawaii Department of—Health (w), Land and Natural Resources, Division of Water and Land Development (w), Transportation (w); Honolulu, City and County—Board of Water Supply (w), Department of Public Works (w); Trust Territory of the Pacific Islands (w)—Commonwealth of the Northern Mariana Islands (w), Federated States of Micronesia (w)—State of Kosrae (w), State of Ponape (w), State of Truk (w), State of Yap (w), Republic of Marshall Islands (w); Republic of Palau (w); University of Hawaii, Water Resources Research Center (w)

Idaho:

Big Lost River Irrigation District (w); Idaho Department of—Health and Welfare (w), Lands (n), Water Resources (w); Idaho Water Resources Board (w); Oakley Canal Company (w); Salmon River Canal Company (w); Teton County, Board of Commissioners (w); The Shoshone-Bannock Tribes, Fort Hall Indian Reservation (w); Water District No. 01, Idaho Falls (w); Water District No. 31, DuBois (w); Water District No. 33, Howe (w); Water District No. 37, Shoshone (w); Water District No. 37-N, Carey (w); Water District No. 65-K, Lake Fork (w)

Illinois:

Bloomington and Normal Sanitary District (w); Cook County, Forest Preserve District (w); Decatur, City of (w); Illinois Department of—Conservation (n), Energy and Natural Resources, State Water Survey Division (w), Nuclear Safety (w), Transportation, Division of Highways (n), Division of Water Resources (n,w); Illinois Environmental Protection Agency (w); Illinois State Geological Survey (n); Springfield, City of (w)

Indiana:

Carmel, Town of (w); Elkhart, City of, Water Works (w); Indiana State Board of Health (w); Indiana Department of—Highways (w), Natural Resources (n)—Division of Water (w), Division of Reclamation (w); Indianapolis, City of, Department of Public Works (w); Purdue University (g)

Iowa:

Cedar Rapids, City of (w); Charles City, City of (w); Clear Lake, City of (w); Des Moines, City of (w); Des Moines Water Works (w); Fort Dodge, City of (w); Iowa Department of—Transportation—Highway Division (w); Water, Air, and Waste Management (w); Iowa Geological Survey (n, w); Iowa State University (w); Marshalltown, City of (w); Sewage Disposal Plant, Waterloo (w); Sioux City, City of (w); University of Iowa, University Physical Plant (w); University Hygenic Laboratory (w); Waterloo, City of (w); West-Central Iowa Rural Water Association (w)

Kansas:

Arkansas River Compact Administration (w); Harvey, County of (w); Hays, City of (w); Kansas Department of—Health and Environment (w), Transportation (w); Kansas Geological Survey (w); Kansas State Board of Agriculture, Division of Water Resources (w); Kansas Water Office (w); Kansas-Oklahoma-Arkansas River Commission (w); Sedgwick, County (w); Southwest Kansas GWMD No. 3 (w); Western Kansas GWMD No. 1 (w); Wichita, City of, Flood Control Maintenance (w)

Kentucky:

Elizabethtown, City of (w); Kentucky Department of—Natural Resources and Environmental Protection Cabinet (w), Transportation Cabinet, Division of Design (w); Louisville, City of (w); University of Kentucky, Kentucky Geological Survey (n,w); University of Louisville (w)

Louisiana:

Baton Rouge City-Parish Government (w); Capital-Area Groundwater Conservation Commission (w); Louisiana Department of—Natural Resources—Geological Survey (g,w); Office of Environmental Affairs, Water Pollution Control Division (w); Transportation and Development—Office of Highways (w), Office of Public Works (n,w); Louisiana State Planning Office (n); Sabine River Compact Administration (w)

Maine:

Androscoggin Valley Regional Planning Commission (w); Cobbossee Watershed District (w); Maine Department of—Conservation, Geological Survey (n,w), Environmental Protection (w); Wilton, Town of (w)

Maryland:

Anne Arundel County, Planning and Zoning Office (w); Baltimore County—Department of Permits and Licenses (w), Department of Public Works (w), Office of Planning and Zoning (w); Calvert County (w); Caroline County (w); Carroll County, Board of County Commissioners (w); Howard County, Department of Public Works (w); Maryland Department of—Health and Mental Hygiene, Office of Environmental Programs (w), Transportation, State Highway Administration (w); Maryland Energy Administration (w); Maryland Geological Survey (n, w); Maryland Water Resources Administration (w); Montgomery County—Department of Environmental Protection, Office of Environmental and Energy Planning (w), Division of Pollution Control (w); Poolesville, Town of (w); St. Marys County, County Commissioners (w); Upper Potomac River Commission (w); Washington Suburban Sanitary Commission (w)

Massachusetts:

Barnstable County, County Commissioners (w); Cape Cod Planning and Economic Development Commission (w); Falmouth, Town of (w); Massachusetts Department of Public Works—Division of Highways (w), Division of Research and Materials (w); Massachusetts State Water Resources Commission—Division of Water Pollution Control (w), Division of Water Resources (w); Metropolitan District Commission, Water Division (w)

Michigan:

Ann Arbor, City of (w); Battle Creek, City of (w); Clare, City of (w); Coldwater, City of, Board of Public Utilities (w); Dickinson County, Board of Commissioners (w); Elsie, Village of (w); Flint, City of, Water Supply and Pollution Control, Department of Public Works and Utilities (w); Genesee County Drain Commission, Division of Water and Waste Services (w); Huron-Clinton Metropolitan Authority (w); Imlay, City of (w); Kalamazoo, City of, Department of Public Utilities (w); Lansing, City of, Board of Water and Light, Water and Stream Division (w); Macomb County (w); Mason, City of (w); Michigan Department of—Agriculture, Soil and Water Conservation Division (w), Natural Resources—Geological Survey Division (w), Office of Budget and Federal Aid (w); Transportation (w); Oakland County, Drain Commission (w); Otsego County, Road Commission (w); Portage, City of (w); St. Johns, City of (w); Van Buren County, Board of Commissioners (w); Ypsilanti, City of (w)

Minnesota:

Bassett Creek Watershed Management Organization (w); Carnelian-Marine Watershed District (w); Coon Creek Watershed District (w); Eagan, City of (w); Elm Creek Conservation Commission (w); Fond Du Lac Reservation Bus. Comm. (w); Iron Range Resources Rehabilitation Board (w); Metropolitan Council of the Twin Cities Area (w); Metropolitan Waste Control Commission (w); Middle River-Snake River Watershed District (w); Minnesota Department of—Energy, Planning and Development (w), Health (w), Natural Resources (w), Transportation (w); Minnesota Geological Survey (w); Minnesota Pollution Control Agency (w); Minnesota Waste Management Board (w); Morrison County, Soil and Water Conservation District (w); Red Lake Watershed District (w); St. Louis Park, City of (w); University of Minnesota (w); Wesmin Resource, Conservation and Development Association (w); White Earth Reservation Bus. Comm. (w)

Mississippi:

Harrison County—Board of Supervisors (w), Development Commission (w); Jackson, City of (w); Jackson County—Board of Supervisors (w), Port Authority (w); Mississippi Department of—Highways (w), Natural Resources—Bureau of Geology (w), Bureau of Land and Water Resources (w), Bureau of Pollution Control (w); Mississippi Research and Development Center (n,w); Natchez, City of (w); Pat Harrison Waterway District (w); Pearl River Valley Water Supply District (w)

Missouri:

Helena, City of (w); Little River Drainage District (w); Missouri Department of—Conservation (w), Natural Resources—Division of Environmental Quality, Lab Services Program (w), Division of Geology and Land Survey (n,w), Land Reclamation Commission (w); Missouri Highway and Transportation Commission (w); Springfield, City of—City Utilities, Engineering Department (w)

Montana:
Helena, City of (w); Montana Bureau of Mines and Geology (w); Montana Department of—Fish, Wildlife, and Parks (w), Health and Environmental Sciences (w), Highways (w), Natural Resources and Conservation (w), State Lands (w); Salish and Kootenai Tribes of Flathead Reservation (w); Wyoming State Engineer (w)

Nebraska:
Central Platte Natural Resources District (w); Kansas-Nebraska Big Blue River Compact Administration (w); Lincoln, City of (w); Little Blue Natural Resources District (w); Lower Platte Natural Resources District (w); Lower Republican Natural Resources District (w); Nebraska Department of—Environmental Control (w), Health (w); Water Resources (w); Nebraska Natural Resources Commission (w); Tri-Basin Natural Resources District (w); Twin Platte Natural Resources District (w); University of Nebraska, Conservation and Survey Division (w); Upper Loup Natural Resources District (w)

Nevada:
California Regional Water Quality Control Board, Lahontan Region (w); Carson City, Department of Public Works (w); Churchill County (w); Douglas County, Department of Planning (w); Fallon, City of (w); Nevada Bureau of Mines and Geology (g,n,w), Nevada Department of—Conservation and Natural Resources—Division of Environmental Protection (w), Division of Water Resources (w); Transportation (w); Reno, City of (w); Washoe County, Council of Governments (w)

New Hampshire:
Conway, Town of (w); Nashua Regional Planning Commission (w); New Hampshire Water Resources Board (w); Water Pollution Control Commission (w)

New Jersey:
Bergen, County of (w); Bridgewater, Township of (w); Camden County, Board of Chosen Freeholders (w); Cranford, Township of (w); Logan, Township of (w); Morris County, Municipal Utilities Authority (w); New Jersey Department of Environmental Protection, Division of Water Resources (w); North Jersey District Water Supply Commission (w); Passaic Valley Water Commission (w); Somerset County, Board of Chosen Freeholders (w); West Windsor Township, Environmental Commission (w)

New Mexico:
Alamo Navajo Chapter (w); Alamogardo, City of (w); Albuquerque, City of (w); Albuquerque Metropolitan Arroyo Flood Control Authority (w); Bernalillo County (w); Costilla Creek Compact Commission (w); Jemez River Indian Water Authority (w); Las Cruces, City of (w); Navajo Indian Nation (w); New Mexico Bureau of Mines and Mineral Resources (w); New Mexico Environmental Improvement Division (w); New Mexico Department of Highways (w); Office of State Engineer (w); Pecos River Commission (w); Pueblo of Acoma (w); Pueblo of Laguna (w); Pueblo of Zuni (w); Raton, City of (w); San Juan County (w); Santa Fe Metropolitan Water Board (w); Veremejo Conservacy District (w)

New York:
Albany, City of, Department of Water and Water Supply (w); Auburn, City of (w); Brookhaven, Town of (w); Chautauqua, County of, Department of Planning and Development (w); Clarence, Town of (w); Cornell University—Department of Natural Resources (w), Department of Utilities (w); Cortland, County of, Planning Department (w); Erie County, Division of Environmental Control, Department of Environment and Planning (w); Hudson-Black River Regulating District (w); Irondequoit Bay Pure Waters (w); Kirkwood, Town of (w); Kiryas Joel, Village of (w); Long Island Regional Planning Board (w); Monroe, County of—Engineering Department (w), Water Authority (w); Nassau, County of, Department of Public Works (w); Newstead, Town of (w); New York City—Department of Environmental Protection, Air Resources-Water Resources-Energy (w), Department of Sanitation, Office of Resource Recovery (w); New York State Department of—Environmental Conservation—Division of Air (w), Division of Water (w); Water Research Bureau (w); Transportation, Bridge and Construction Bureau (w); New York State Energy Resources and Development Authority (w); New York State Power Authority (w); Nyack, Village of, Board of Water Commissioners (w); Onondaga, County of—Department of Drainage (w), Environmental Management Council (w), Water Authority (w); Oswego, County of, Planning Board (w); Rockland, County of, Drainage Agency (w); Seneca Nation of Indians (w); Shelter Island, Town of (w); Suffolk, County of—Department of Health Sciences (w), Water Authority (w); Susquehanna River Basin Commission (w); Temporary State Commission on Tug Hill (w); Ulster, County of, County Legislators (w); University of the State of New York, Regents Research Inc. (w); Westchester, County of—Department of Health (w), Department of Public Works (w)

North Carolina:
Ayden, Town of (w); Charlotte, City of (w); Durham, City of, Department of Water Resources (w); Farmville, Town of (w); Greene County (w); Greensboro, City of (w); Greenville Utilities (w); Kinston, City of (w); LaGrange, Town of (w); New Bern, City of (w); North Carolina State Department of—Human Resources (w), Natural Resources and Community Development (n,w), Transportation, Division of Highways (w); Pinetops, Town of (w); Rocky Mount, City of (w); Snow Hill, Town of (w); Stantonsburg, Town of (w)

North Dakota:
Burleigh County, Water Resources District (w); Dickinson, City of (w); North Dakota Geological Survey (w); North Dakota State University (w); Oliver County, Board of Commissioners (w); Public Service Commission (w); State Department of Health (w); State Water Commission (w); University of North Dakota (w)

Northern Mariana Islands: (See Hawaii)

Ohio:
Canton, City of, Water Department (w); Columbus, City of—Department of Public Service (w), Division of Water (w); Miami Conservancy District (w); Northeast Ohio Areawide Coordinating Agency (w); Northwood, City of (w); Ohio Department of—Natural Resources—Division of Geological Survey (g,w), Division of Oil (w), Division of Reclamation (w), Division of Water (w); Transportation (w); Ohio Environmental Protection Agency (w); Seneca Soil and Water District (w)

Oklahoma:
Ada, City of (w); Altus, City of (w); Central Oklahoma Master Conservancy District (w); Claremore, City of (w); Fort Cobb Reservoir Master Conservancy District (w); Foss Reservoir Master Conservancy District (w); Lawton, City of (w); Lugert-Altus Irrigation District (w); Mountain Park Master Conservancy District (w); Oklahoma City, City of (w); Oklahoma Conservation Commission (w); Oklahoma Department of—Transportation (n,w); Oklahoma Geological Survey, University of Oklahoma (w); Oklahoma State Health Department (w); Oklahoma Water Resources Board (w); Sapulpa, City of (w); Tulsa, City of (w)

Oregon:
Benton County Board of Commissioners (w); Burnt River Irrigaton District (w); Confederated Tribes of—Umatilla Indian Reservation (w), Warm Springs Indian Reservation (w); Coos Bay-North Bend Water Board (w); Douglas, County of, Department of Public Works (w); Eugene, City of, Water and Electric Board (w); Lane Council of Governments (w); Lane, County of, Office of the Chief Administrator (w); McMinnville, City of, Water and Light Department (w); Oregon Department of—Environmental Quality (w), Fish and Wildlife (w), Geology and Mineral Industries (g,n), Transportation, Highway Division (w); Water Resources (w); Oregon State University (w); Portland, City of, Bureau of Water Works (w); Rajneeshpuram, City of (w); Salem, City of (w); Wasco County People's Utility District (w)

Pennsylvania:

Altoona City Authority (w); Bethlehem, City of (w); Chester, County of, Water Resources Authority (w); Delaware River Basin Commission (w); Harrisburg, City of, Department of Public Works (w); Letort Regional Authority (w); Millcreek, Township of (w); New York State Department of Environmental Conservation (w); Oley Township (w); Philadelphia, City of, Water Department (w); Pennsylvania Department of—Environmental Resources—Mining and Reclamation Bureau (w), Office of Resources Management (w), Soil Wastes and Management Bureau (w), State Parks Bureau (w), Topographic and Geologic Survey Bureau (n,w), Water Quality Management Bureau (w); Pennsylvania State University (g); Susquehanna River Basin Commission (w); Washington County—Conservation District (w), Supervisors (w)

Puerto Rico:

Puerto Rico Aqueduct and Sewer Authority (w); Puerto Rico Department of—Agriculture (w), Health (w), Natural Resources (g,w), Transportation and Public Works (w); Puerto Rico Electric Power Authority (w); Puerto Rico Environmental Quality Board (w); Puerto Rico Industrial Development Company (w); Puerto Rico Land Administrator (w); Puerto Rico Land Authority (w); Puerto Rico Mineral Resources Development Corporation (g); Puerto Rico Planning Board (w); Puerto Rico Rice Corporation (w); Puerto Rico Sugar Corporation (w); Puerto Rico Vegetable Corporation (w); (**See also** Virgin Islands)

Rhode Island:

Narragansett Bay Water Quality Commission (w); Rhode Island State Department of Environmental Management, Division of Water Resources (w); State Water Resources Board (w)

South Carolina:

Charleston, Commission of Public Works (w); Grand Strand Water and Sewer Authority (w); Hilton Head Island, Public Service District No. 1 (w); Myrtle Beach, City of (w); North Myrtle Beach, City of (w); South Carolina State—Department of Highways and Public Transportation (w), Geological Survey (w), Health and Environmental Control (w), Public Service Authority (w), Water Resources Commission (w); Spartanburg Water Works, Commissioners of Public Works (w)

South Dakota:

Black Hills Conservancy Subdistrict (w); East Dakota Conservancy Subdistrict (w); Lower James Conservancy Subdistrict (w); South Dakota Department of—Transporation (n); Water and Natural Resources—Geological Survey Division (w), Water Rights Division (w); Watertown, City of (w)

Tennessee:

Division of Surface Mines (w); Gallatin, City of (w); Lawrenceburg, City of (w); Memphis, City of—Light, Gas, and Water Division (w), Public Works Division (w), Metropolitan Government of Nashville and Davidson County; Shelby, County of (w); Tennessee Department of—Conservation, Geology Division (n,w), Health and Environment (w); Transportation, Bureau of Highways (w); University of Tennessee (w)

Texas:

Abilene, City of (w); Alice, City of (w); Arlington, City of (w); Athens Municipal Water Authority (w); Austin, City of (w); Bexar–Medina–Atascosa Counties, Water Improvement District No. 1 (w); Bistone Municipal Water Supply District (w); Brazos River Authority (w); Cleburne, City of (w); Clyde, City of (w); Coastal Bend Council of Governments (w); Coastal Industrial Water Authority (w); Colorado River Municipal Water District (w); Corpus Christi, City of (w); Dallas, City of, Public Utilities (w); Dallas, County of, Public Works Department (w); Dallas–Fort Worth Airport (w); Edwards Underground Water District (w); El Paso, City of, Public Service Board (w); Franklin, County of, Water District (w); Gainesville, City of (w); Galveston, County of (w); Garland, City of (w); Graham, City of (w); Greenbelt Municipal and Industrial Water Authority (w); Guadalupe–Blanco River Authority (w); Harris, County of, Flood Control District (w); Harris–Galveston Coastal Subsidence District (w); Houston, City of (w); Lavaca–Navidad River Authority (w); Lower Colorado River Authority (w); Lower Neches Valley Authority (w); Lubbock, City of (w); Mackenzie Municipal Water Authority (w); Nacogdoches, City of (w); North Central Texas Municipal Water Authority (w); Northeast Texas Municipal Water District (w); Orange, County of (w); Pecos River Commission (w); Red Bluff Water Power Control District (w); Reeves, County of, Water Improvement District No. 1 (w); Sabine River Authority of Texas (w); Sabine River Compact Administration (w); San Angelo, City of (w); San Antonio, City of—Engineering Department (w), Water Board (w); San Antonio River Authority (w); San Jacinto River Authority (w); Tarrant, County of, Water Control and Improvement District No. 1 (w); Texas Bureau of Economic Geology (g); Texas Department of Water Resources (n, w); Texas Parks and Wildlife Department (w); Titus, County of, Fresh Water Supply District No. 1 (w); Trinity River Authority (w); Upper Guadalupe River Authority (w); Upper Neches River Municipal Water Authority (w); Upper Trinity Basin Water Quality Compact (w); West Central Texas Municipal Water District (w); Wichita, County of, Water Improvement District No. 2 (w); Wichita Falls, City of (w); Wood, County of (w)

Trust Territorv of the Pacific Islands: (See Hawaii)

Utah:

Bear River Commission (w); Department of Transporation (w); Salt Lake, County of—Board of County Commissioners (w), Division of Flood Control and Water Quality (w), Utah Department of—Natural Resources—Geological and Mineral Survey (g,w), Oil, Gas and Mining Division (w), Water Resources Division (w), Water Rights Division (w), Wildlife Resources Division (w)

Vermont:

Agency of Environmental Conservation (n); Vermont Department of Water Resources and Environmental Engineering (w)

Virginia:

Alexandria, City of, Department of Transportation and Environmental Services (w); County of York (w); James City, County of, Department of Public Works (w); James City Service Authority (w); Newport News, City of, Department of Public Utilities (w); Roanoke, City of, Utilities and Operations (w); Southeastern Public Service Authority of Virginia (w); University of Virginia, Department of Environmental Sciences (w); Virginia Department of—Conservation and Economic Development, Division of Mineral Resources (n), Highways and Transportation (w); Virginia State Water Control Board (w); Williamsburg, City of (w)

Virgin Islands:

Department of Public Works (w); Planning Office (w); Virgin Islands, College of (w)

Washington:

Bellevue, City of, Public Works Department (w); Centralia, City of (w); Chatcom County (w); Chelan, County of, Public Utility District No. 1 (w); Everett, City of (w); Fircrest, Town of (w); Hoh Indian Tribe (w); Island, County of, Board of County Commissioners (w); King, County of, Department of Public Works (w); Lewis, County of, Board of Commissioners (w); Makah Tribal Council (w); Municipality of Metropolitan Seattle (w); Pend Oreille, County of, Public Utility District No. 1 (w); Puyallup Indian Nation (w); Quinault Indian Business Committee (w); San Juan County Board of County Commissioners (w); Seattle, City of—Department of Lighting (w), Water Department (w); Skagit, County of (w); Snohomish County (w); Stillaguamish Indian Tribe (w); Tacoma, City of—Public Utilities Department (w), Public Works Department (w); Tulalip Tribal Board of Directors (w); Yakima Tribal Council (w); Washington Department of—Ecology (w), Fisheries (w), Natural Resources (g,n), Transportation (w)

West Virginia:
Marshall County Commission (w); Morgantown, City of, Water Commission (w); West Virginia Department of—Highways (w), Natural Resources—Division of Reclamation (w), Division of Water Resources (w); West Virginia Geological and Economic Survey (w)

Wisconsin:
Bad River Tribal Council (w); Dane, County of—Department of Public Works (w), Regional Planning Commission (w); Delavan Lake Sanitary District (w); Forest County Potawatomi Community (w); Green Bay Metropolitan Sewerage District (w); Green Lake Sanitary District (w); Hills Lake District Association (w); Lac du Flambeau Indian Reservation (w); Madison Metropolitan Sewage District (w); Madison Water Utility (w); Menominee Indian Tribe of Wisconsin (w); Middleton, City of (w); Morris Lake Management District (w); Slinger, Village of (w); Southeastern Wisconsin Regional Planning Commission (w); University of Wisconsin, Extension, Geological and Natural History Survey (n,w); University of Wisconsin, Milwaukee (w); Wisconsin Department of—Natural Resources (n,w), Transportation (n)—Bridge Section (w), Division of Highways (w)

Wyoming:
Buffalo, City of (w); Water Development Commission (w); Wyoming Department of—Agriculture (w), Economic Planning and Development (w), Environmental Quality (w), Highways (w); Wyoming State Engineer (n,w)

FEDERAL COOPERATORS

Central Intelligence Agency (g,n)

Department of Agriculture:
Agricultural Stabilization and Conservation Service (n); Economics, Statistics, and Cooperatives Service (n, w); Forest Service (n,w); Graduate School (w); Agricultural Research Service (w); Soil Conservation Service (g,n,w)

Department of the Air Force:
Air Force Academy (w); Bolling Air Force Base (g); Hanscom Air Force Base (g); Headquarters, AFTAC/AC (g); Vandenberg Air Force Base (w); Wurtsmith Air Force Base (w)

Department of the Army:
Armament Research and Development Command (w); Avionics R and D Activity (g); Coastal Engineering Research Center (g); Corps of Engineers (g,w); Fort Belvoir (n); Fort Bliss (w); Fort Carson Military Reservation (w); Mobility Equipment Research and Development Command (g); Research Office, Triangle Park, N.C. (g); Waterways Experiment Station (g); White Sands Missile Range (w); CE–New Orleans (n)

Department of Commerce:
Census (n); Coastal Plains Regional Action Planning Commission (g); National Bureau of Standards (g); National Ocean Survey (n); National Oceanic and Atmospheric Administration (n), National Marine (w); Fisheries Service (n,w); National Weather Service (g,n,w)

Department of Defense Agencies:
Defense Advanced Research Projects Agency (g); Defense Mapping Agency (g,n); Defense Nuclear Agency (g); Defense Intelligence Agency (g)

Department of Energy:
Albuquerque Operations Office (g,w); Nuclear Regulatory Commission (g,w); Bonneville Power Administration (w); Chicago Operations Office (w); Idaho Operations Office (w); Lawrence Livermore Laboratory (g); Nevada Operations Office (g,n,w); Oak Ridge Operations Office (w); Office of Energy Research (g); Procurement Operations Office (g); Richland Operations Office (g,w); San Francisco Operations (g); Sandia National Laboratories (g); United States Arms Control and Disarmament Agency (g); Western Area Power Administration (g)

Department of Health and Human Services (w)

Department of the Interior:
Bureau of Indian Affairs (g,n,w); Bureau of Land Management (g,n,w); Bureau of Mines (g,n,w); Bureau of Reclamation (g,w); Minerals Management Service (g,w); National Park Service (g,n,w); Office of the Secretary (g,w); Office of Surface Mining Reclamation and Enforcement (g,w); U.S. Fish and Wildlife Service (g,n,w); Water and Power Resources Service (g)

Department of Justice (n,w)

Department of the Navy:
Naval Explosive Ordnance Disposal Test Center (g); Naval Oceanographic Office (g); Naval Weapons Center, China Lake (g,n,w); Office of Naval Research (g); U.S. Marine Corps, Camp Pendleton (w)

Department of State:
Agency for International Development (g,w); International Boundary and Water Commission, U.S. and Mexico (w); International Joint Commission, U.S. and Canada (w)

Department of Transportation:
Federal Highway Administration (g,n,w); St. Lawrence Seaway Development Corporation (w); U.S. Coast Guard (w)

Department of Treasury:
U.S. Customs Service (n)

Environmental Protection Agency (n):
Corvallis Environmental Research Laboratory (w); Environmental Monitoring Systems Laboratory (g); Office of Environmental Engineering and Technology (g); Office of Monitoring and Technical Suoport (w)

Federal Emergency Management Agency (g, w)

Federal Energy Regulating Commission Licensees (w)

General Services Administration (w)

Missouri Basin States Association (w)

National Aeronautics and Space Administration (g,n,w)

National Science Foundation (g,n,w)

Tennessee Valley Authority (n,w)

Veterans Administration (g,w)

OTHER COOPERATORS AND CONTRIBUTORS

Government of American Samoa (w)

Government of Guam (w)

Government of Peru (g)

Government of Saudi Arabia (g,n,w)

Government of Venezuela (w)

People's Republic of China (g)

Puerto Rico:
Puerto Rico Aqueduct and Sewer Authority (w); Puerto Rico Department of Agriculture (w); Puerto Rico Department of Health (w); Puerto Rico Department of Natural Resources (g,w); Puerto Rico Department of Transportation and Public Works (w); Puerto Rico Electric Power Authority (w); Puerto Rico Environmental Quality Board (w); Puerto Rico Industrial Development Company (w); Puerto Rico Land Authority (w); Puerto Rico Mineral Resources Development Corporation (g); Puerto Rico Planning Board (w); Puerto Rico Sugar Corporation (w)

Trust Territories of the Pacific Islands (w):
Commonwealth of the Northern Mariana Islands (w); Federated States of Micronesia (w)—State of Kosrae (w), State of Ponape (w), State of Truk (w), State of Yap (w); Republic of Palau (w)

United Nations:
United Nations Development Program (g,w); UNESCO (w); World Meteorological Organization (w)

Virgin Islands:
College of the Virgin Islands (w); Virgin Islands Department of Public Works (w); Virgin Islands Planning Office (w)

Budgetary and Statistical Data

TABLE 1. *Geological Survey budget for fiscal years 1979 to 1984, by activity and sources of funds*
(Dollars in thousands; totals may not add due to rounding)

Budget activity	1979	1980	1981	1982	1983	1984
Total	**$764,718**	**$782,136**	**$769,757**	**$661,842**	**$556,054**	**$596,177**
Direct program	634,886	639,143	623,057	509,983	396,909	423,885
Reimbursable program	129,832	142,993	146,700	151,859	159,145	172,292
States, counties, and municipalities	44,124	46,849	48,700	50,418	51,972	55,801
Miscellaneous non-Federal sources	15,789	16,817	19,605	24,376	21,215	21,142
Other Federal agencies	69,919	79,327	78,395	77,065	85,958	95,349
National Mapping, Geography, and Surveys	**74,566**	**82,683**	**89,177**	**88,133**	**91,611**	**112,447**
Direct program	65,584	72,759	77,449	77,687	81,138	90,985
Reimbursable program	8,982	9,924	11,727	10,446	10,473	21,462
States, counties, and municipalities	3,371	3,083	2,985	3,000	2,700	2,700
Miscellaneous non-Federal sources	597	610	1,095	1,100	1,204	2,362
Other Federal agencies	5,014	6,231	7,648	6,346	6,569	16,400
Geologic and Mineral Resource Surveys and Mapping	**178,556**	**193,652**	**208,287**	**212,355**	**206,517**	**217,584**
Direct program	134,846	146,963	162,756	163,731	159,190	164,354
Reimbursable program	43,710	46,689	45,531	48,624	47,327	53,230
States, counties, and municipalities	584	640	758	480	490	988
Miscellaneous non-Federal sources	10,914	11,258	13,192	16,844	14,293	15,030
Other Federal agencies	32,212	34,791	31,761	31,300	32,544	37,212
Water Resources Investigations	**168,598**	**184,871**	**194,016**	**190,096**	**199,697**	**220,390**
Direct program	96,847	108,664	115,458	108,637	115,096	129,441
Reimbursable program	71,751	76,207	78,558	81,459	84,601	90,949
States, counties, and municipalities	40,156	43,126	45,138	46,938	48,782	52,113
Miscellaneous non-Federal sources	1,673	1,778	2,088	2,679	3,914	3,600
Other Federal agencies	29,922	31,303	31,332	31,842	31,905	35,236
Conservation of Lands and Minerals	**85,484**	**106,395**	**127,001**	**130,468**	———	———
Direct program	85,362	105,928	125,739	129,868	------	------
Reimbursable program	122	467	1,262	600	------	------
Miscellaneous non-Federal sources	------	12	29	210	------	------
Other Federal agencies	122	455	1,233	390	------	------
Office of Earth Sciences Applications	**23,965**	**23,734**	**23,205**	**20,853**	**18,452**	———
Direct program	19,959	18,935	18,849	14,359	11,132	------
Reimbursable program	4,006	4,799	4,356	6,494	7,320	------
States, counties, and municipalities	13	------	------	------	------	------
Miscellaneous non-Federal sources	2,333	2,808	3,139	3,482	1,728	------
Other Federal agencies	1,600	1,991	1,217	3,012	5,592	------
National Petroleum Reserve in Alaska						
Direct Program	**216,886**	**169,845**	**107,001**	**2,196**	———	———
Allocation transfer	------	------	------	------	------	------
Reimbursable program (Federal)	------	------	------	------	------	------
General Administration	**3,661**	**3,776**	**3,896**	**3,407**	**16,313**	**15,962**
Direct program	3,661	3,776	3,896	3,407	14,931	15,642
Reimbursable program (Federal)	------	------	------	------	1,382	320
Facilities	**11,741**	**12,273**	**11,909**	**10,093**	**9,167**	**10,608**
Direct program	11,741	12,273	11,909	10,098	9,022	10,463
Reimbursable program	------	------	------	------	145	145
Miscellaneous services to other accounts	**1,261**	**4,907**	**5,266**	**4,236**	**7,917**	**6,186**
Reimbursable program	1,261	4,907	5,266	4,236	7,917	6,186
Miscellaneous non-Federal sources	272	351	62	61	96	150
Other Federal agencies	989	4,556	5,204	4,175	7,821	6,036
Barrow Area Gas Operations	———	———	———	———	**6,400**	**13,000**
Direct program	------	------	------	------	6,400	13,000

[1] Includes 1982 appropriation for Minerals Management Service.

TABLE 2. *Geological Survey reimbursable program funds from other Federal agencies for fiscal years 1979 to 1984, by agency*
(Dollars in thousands)

Budget activity	1979	1980	1981	1982	1983	1984
Total	**$69,919**	**$79,326**	**$78,395**	**$76,675**	**$85,958**	**$95,349**
Department of Agriculture	2,619	3,878	3,567	2,675	2,774	2,770
Department of Commerce	141	276	------	------	111	910
National Oceanic and Atmospheric Administration	1,464	2,388	823	1,781	5,750	6,139
Ozarks Regional Commission	------	76	------	------	------	------
Department of Defense	16,760	17,447	18,490	21,459	25,429	33,707
Department of Energy	15,338	14,406	10,885	10,529	5,858	13,828
Bonneville Power Administration	48	61	81	75	103	120
Department of Housing and Urban Development	1,967	302	188	------	------	------
Department of the Interior	17,746	22,926	22,553	20,328	23,955	16,167
Bureau of Indian Affairs	4,345	9,295	3,999	5,001	4,796	4,299
Bureau of Land Management	9,712	7,807	13,800	10,551	7,150	3,446
Bureau of Mines	240	297	299	275	200	56
Bureau of Reclamation	1,975	2,257	2,231	1,800	3,411	3,524
Minerals Management Service	------	------	------	------	5,284	2,347
National Park Service	771	818	1,121	1,015	1,957	1,037
Office of the Secretary	82	203	154	100	223	244
Office of Surface Mining	21	1,563	469	1,176	606	95
U.S. Fish and Wildlife Service	600	686	480	410	328	1,119
Department of State	1,455	2,449	2,272	3,445	573	700
Department of Transportation	149	291	273	500	483	600
Environmental Protection Agency	2,873	2,645	1,259	675	883	1,012
National Aeronautics and Space Administration	4,033	2,793	5,065	3,885	3,716	3,999
National Science Foundation	896	1,211	2,001	1,958	1,300	774
Nuclear Regulatory Commission	1,583	1,325	1,781	1,544	2,272	2,003
Tennessee Valley Authority	261	243	317	290	151	250
Miscellaneous Federal agencies	1,645	2,105	3,717	3,431	4,882	6,334
Miscellaneous services to other accounts	989	4,556	5,204	4,175	7,821	6,036

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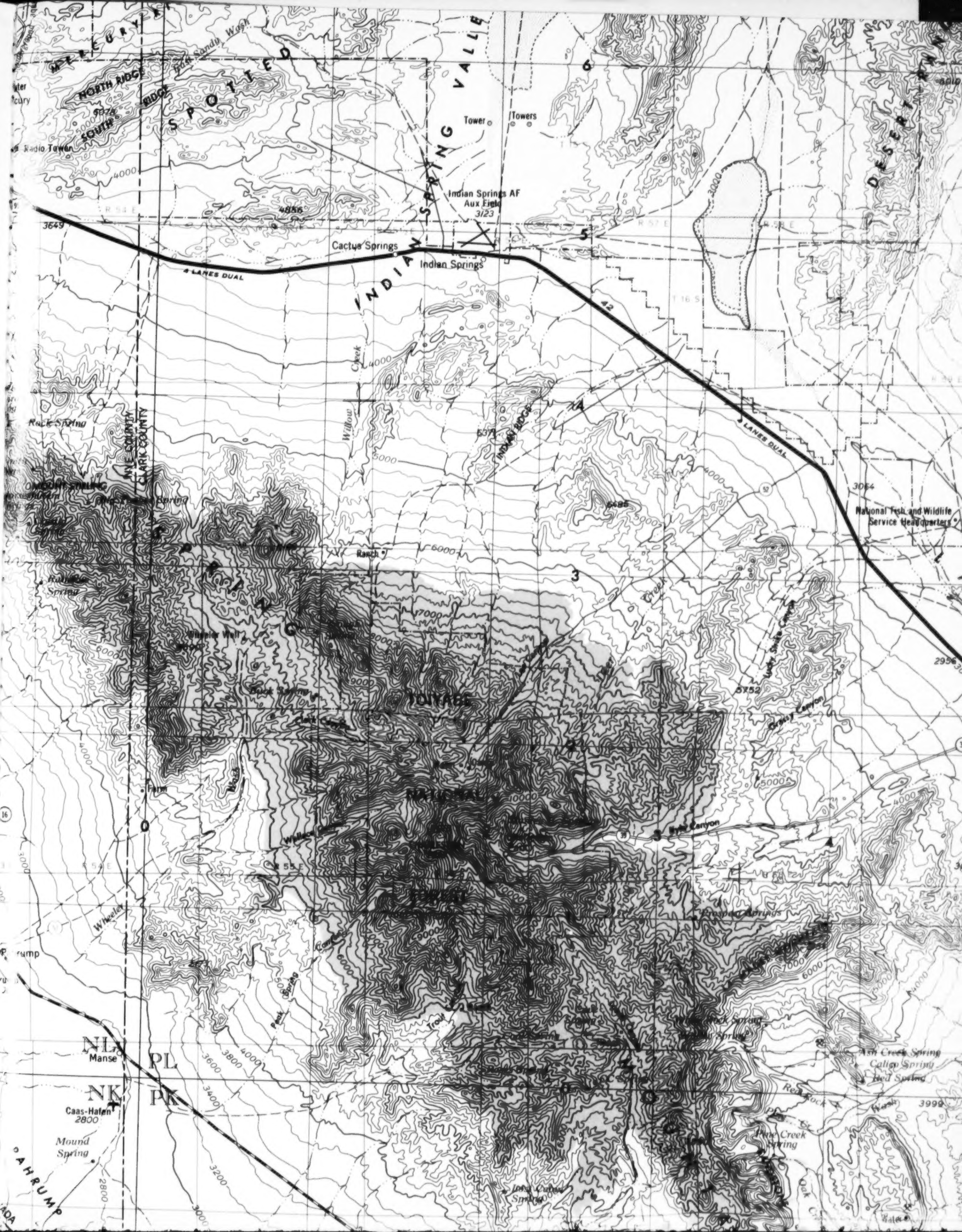
March 3, 1849

As the Nation's principal conservation agency, the Department of the Interior has responsibility for most of our nationally owned public lands and natural resources. This includes fostering the wisest use of our land and water resources, protecting our fish and wildlife, preserving the environmental and cultural values of our national parks and historical places, and providing for the enjoyment of life through outdoor recreation. The Department assesses our energy and mineral resources and works to assure that their development is in the best interest of all our people. The Department also has a major responsibility for American Indian reservation communities and for people who live in Island Territories under U.S. Administration.



SPOTTED RANGE
NORTH RIDGE
SOUTH RIDGE
Radio Tower
INDIAN SPRING VALLEY
Tower
Towers
Indian Springs AF Aux Field
3123
Cactus Springs
Indian Springs
4 LANES DUAL
42
3649
4856
DESERT RANGE
Willow Creek
INDIAN RIDGE
Rock Spring
NYE COUNTY
CLARK COUNTY
MOUNT SPRING
Ranch
3064
National Fish and Wildlife Service Headquarters
SPRING MOUNTAINS
Wheeler Well
Buck Spring
TOIYABE NATIONAL FOREST
Farm
Wallace Canyon
Kyle Canyon
Grassy Canyon
Prospect Springs
Trout Canyon
Peak Spring
Wheeler
Pahrump
NL
Manse
PL
NK
PK
Caas-Hafen
2800
Mound Spring
PAHRUMP
Ash Creek Spring
Calico Spring
Red Spring
Red Rock
Pine Creek Spring
Oak Cr
3999
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